0889

PB 205 256

Long-Path Spectrophotometric Instrumentation for In-Situ Monitoring of Gaseous Pollutants in the Urban Atmosphere

BSR 3027
Final Report
October 1970
Ann Arbor, Michigan

By:

Arnold Prostak
Robert H. Dye

Bendix Aerospace Systems Division

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
Springfield, Va. 22151

93

BIBLIOGRAPHIC DATA SHEET

1. Report No. APTD-0889

2.

3. Recipient's Accession No.

4. Title and Subtitle

Long-Path Spectrophotometric Instrumentation for In-Situ Monitoring of Gaseous Pollutants in the Urban Atmosphere

5. Report Date October 1970

6.

7. Author(s) Arnold Prostak, Robert H. Dye

8. Performing Organization Rept. No. BSR 3027

9. Performing Organization Name and Address

Bendix Aerospace Systems Division
Ann Arbor, Michigan

10. Project/Task/Work Unit No.

11. Contract/~~Grant~~ No. CPA 22-69-55

12. Sponsoring Organization Name and Address

Department of Health, Education, and Welfare
Public Health Service
National Air Pollution Control Administration

13. Type of Report & Period Covered Final

14.

15. Supplementary Notes DISCLAIMER: This report was furnished to the National Air Pollution Control Administration, in fulfillment of Contract No. CPA 22-69-55.

16. Abstracts

A long-path spectrophotometric instrument is described for the quantitative measurement of ozone and other infrared absorbing gases (such as sulfur dioxide) in unconfined ambient air. A continuous variable filter wheel is used for wavelength selection from 7 to 14 microns ~~u m~~. The instrument can be used with an active source at a range from 0.4 to over 1.6 km or it can be used to examine passively the radiant emittance from natural sources. A minicomputer is programmed to control the instrument and analyze the data in real time. The output of spectra or pollutant concentration is on a cathode ray tube, a teletypewriter, and/or punched paper tape. The instrument is sensitive to ozone concentrations ranging from 20 microgram/cu. m. (0.01 ppm) to 2000 microgram/cu.m. (1 ppm), with a measured noise of less than 4 microgram/cu.m. and a time constant of about two minutes.

17. Key Words and Document Analysis. 17a. Descriptors

Air pollution
Spectrophotometry
Monitors
Urban areas
Ozone
Sulfur dioxide
Infrared spectroscopy
Data processing

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 13B, 14/02

18. Availability Statement Unlimited

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 118

22. Price

FORM NTIS-35 (10-70)

USCOMM-DC 40329-P71

C

Long-Path Spectrophotometric Instrumentation for In-Situ Monitoring of Gaseous Pollutants in the Urban Atmosphere

BSR 3027
Final Report
October 1970
Ann Arbor, Michigan

By:

Arnold Prostak
Robert H. Dye

Prepared for: National Air Pollution Control Administration
Environmental Health Service,
Public Health Service,
Department of Health, Education, and Welfare

Pursuant to: Contract No. CPA 22-69-55

Bendix **Aerospace**
Systems Division

FOREWORD

The work described in this report was performed between April 1969 and September 1970. The Government Project Officer was Mr. John S. Nader and the Assistant Project Officer was Dr. Harold M. Barnes, Jr., both of the National Air Pollution Control Administration.

ABSTRACT

A description is given of a long-path spectrophotometric instrument is described for the quantitative measurement of ozone and other infrared absorbing gases (such as sulfur dioxide) in unconfined ambient air. A continuous variable filter wheel is used for wavelength selection from 7 to 14 μm. The instrument can be used with an active source at a range from 0.4 to over 1.6 km or it can be used to examine passively the radiant emittance from natural sources. A minicomputer is programmed to control the instrument and analyze the data in real time. The output of spectra or pollutant concentration is on a cathode ray tube, a teletypewriter, and/or punched paper tape. The instrument is sensitive to ozone concentrations ranging from 20 μg/m^3 (0.01 ppm) to 2000 μg/m^3 (1 ppm), with a measured noise of less than 4 μg/m^3 and a time constant of about two minutes.

microgram/cu. m.

CONTENTS

Page

1. INTRODUCTION 1-1
2. SYSTEM DESCRIPTION 2-1
    - 2.1 TRANSMITTER 2-6
    - 2.2 RECEIVER 2-7
    - 2.3 ELECTRONICS 2-14
        - 2.3.1 Source 2-14
        - 2.3.2 Receiver 2-14
        - 2.3.3 Central Control Electronics 2-15
        - 2.3.4 Signal Processing 2-21
3. DISCUSSION OF COMPUTER PROGRAM 3-1
    - 3.1 PROGRAM FLOW 3-3
        - 3.1.1 INIT Routine 3-4
        - 3.1.2 Auxiliary Routine (AUX) 3-4
        - 3.1.3 Interrupt Service Routine (ISR) 3-21
        - 3.1.4 Subroutines 3-22
    - 3.2 DESCRIPTION OF OUTPUT 3-22
4. OFF-LINE DATA PROCESSING 4-1
5. CALCULATION AND MEASUREMENT OF INSTRUMENT SIGNAL AND NOISE 5-1
    - 5.1 ACTIVE SIGNAL 5-1
    - 5.2 PASSIVE SIGNAL 5-4
    - 5.3 NOISE 5-5
6. RESULTS 6-1
    - 6.1 INSTRUMENT RESPONSE 6-1
    - 6.2 ACTIVE-MODE SPECTRA 6-1
    - 6.3 PASSIVE-MODE SPECTRA 6-22
    - 6.4 ABSORPTION COEFFICIENT OF OZONE 6-22
    - 6.5 EVALUATION OF OZONE READOUT 6-24
7. DISCUSSION AND RECOMMENDATIONS 7-1

APPENDIX DETAILED OPERATING INSTRUCTIONS A-1

ILLUSTRATIONS

Figure	Title	Page
1-1	Block Diagram of Ozone Monitor	1-2
2-1	Transmitter Unit	2-2
2-2	Receiver Unit	2-3
2-3	Electronics Console	2-5
2-4	Transmittance and Reflectance of Beam Splitter and Auxiliary Filter	2-8
2-5	Filter Wheel Data Report	2-9
2-6	Filter Wheel Transmittance	2-10
2-7	Automatic Range Control Amplifier	2-16
2-8	Synchronous Detectors, Integrators, and Multiplexer	2-17
2-9	Synchronization Block Diagram	2-19
2-10	Computer Interface Logic	2-20
3-1	Initialize Routine	3-5/3-6
3-2	Auxiliary Routine	3-7/3-8
3-3	Interrupt Service Routine	3-9/3-13
3-4	Subroutines	3-14
4-1	Output From HEXED Program	4-2
4-2	Output From OMAS Program	4-3/4-4
4-3	Output From Regression Program	4-6/4-7
4-4	Output From Coefficient Converter Program	4-8
6-1	Response Curve of Instrument With Transmitter	6-2
6-2	Spectra Obtained With Ozone Monitor	6-3/6-12
6-3	Mean Spectra for ID 60 and 79	6-13
6-4	Polystyrene Spectra	6-14
6-5	Spectra With Ozone Cell in Beam	6-15/6-21
6-6	Passive Spectra	6-23
6-7	Ozone Absorption Coefficients	6-25
6-8	Ozone Monitor Readings	6-27
A-1	Oscilloscope Trace From AFC Phase Demodulator	A-11

TABLES

Table	Title	Page
2-1	Approximate Source Temperature	2-7
2-2	Filter Wheel Wavelengths	2-11/2-12
3-1	Glossary of Computer Program Symbols	3-15/3-17
3-2	Program Branch Explanations	3-18/3-19
6-1	Calculation of K(9.7μm) From Spectra	6-24
A-1	Test Panel Switch Position Identification	A-9

BLANK PAGE

SECTION 1

INTRODUCTION

The Aerospace Systems Division of The Bendix Corporation has built a long-path spectrophotometric instrument for the quantitative measurement of ozone in unconfined ambient air. This work was performed pursuant to Contract No. CPA 22-69-55 with the National Air Pollution Control Administration, Environmental Health Service, Public Health Service, Department of Health, Education, and Welfare.

The instrument is a single-beam infrared spectrophotometer with a sample space up to 1.6 km (1 mile) long and a minicomputer to analyze the results in real time. The instrument is sensitive to ozone concentrations ranging from 20 $\mu g/m^3$ (0.01 ppm) to 2000 $\mu g/m^3$ (1 ppm). The instrument can also be used as a spectroradiometer to measure the spectral radiant power received from passive sources. This versatile instrument is designed for use in a wide range of research studies, but for brevity will sometimes be referred to here as an Ozone Monitor. Figure 1-1 shows a block diagram of the instrument.

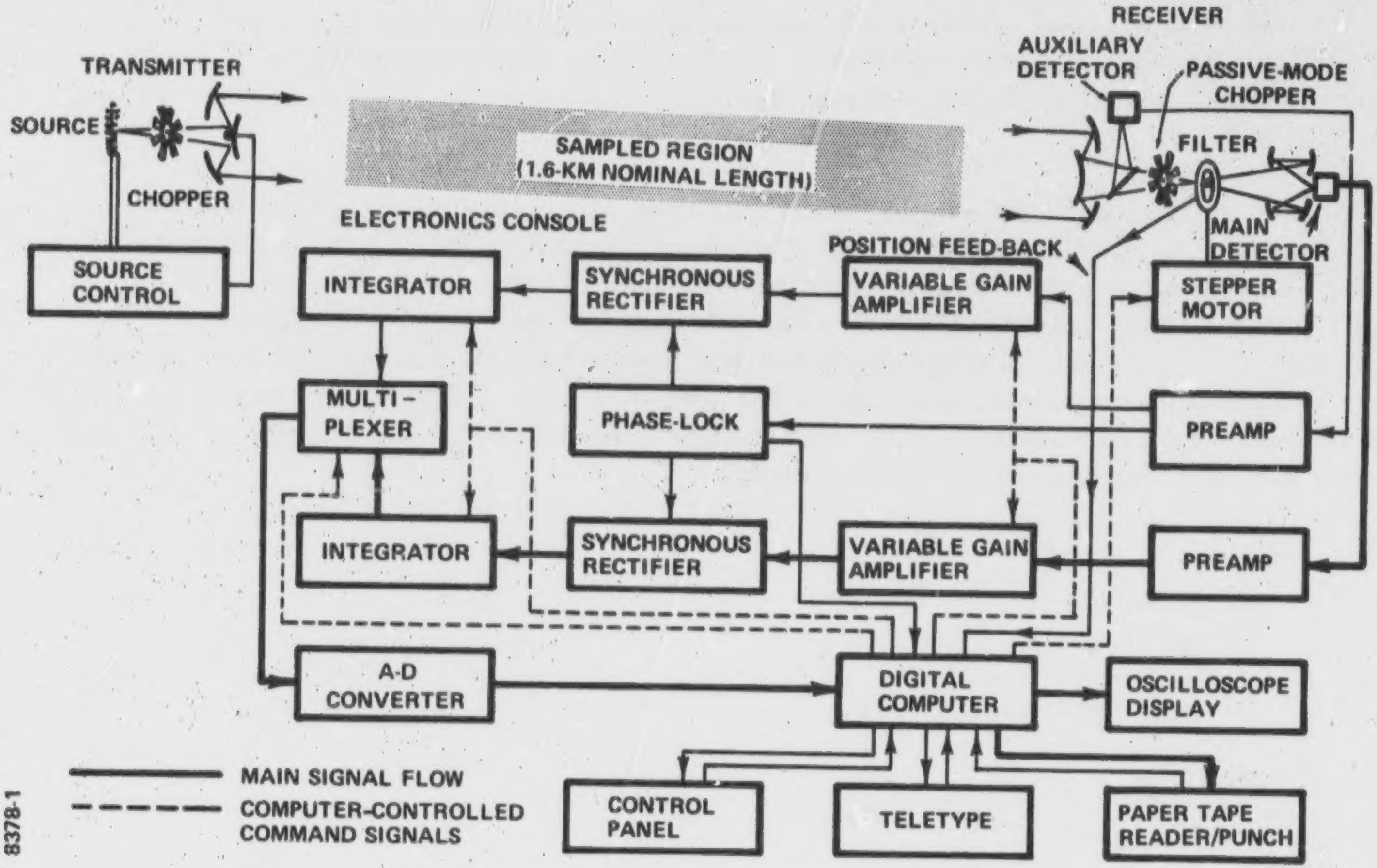


Figure 1-1 Block Diagram of Ozone Monitor

SECTION 2

SYSTEM DESCRIPTION

The source or transmitter unit utilizes an electrically heated silicon carbide and alumina source at the focus of a 32 cm (12.5 in.) diameter optical system. The source radiant power is chopped at a frequency of 480 cps. The transmitter projects a beam of radiant power to the receiver which is normally from 400 to 1600 m distant. The transmission spectrum of this optical path can be obtained, and material present in this path that possesses specific absorption bands in the 7 to 14 micrometer (μm) wavelength range of the instrument can be detected and measured by its spectrum. Figure 2-1 shows a photograph of the transmitter.

The receiver contains 27 cm (10.5 in.) diameter collecting optics which focus the received radiant power onto a continuously variable filter wheel.* This wheel consists of a multilayer interference filter on a germanium substrate, and the wavelength of the pass-band of this filter varies as one goes around the wheel. The wheel provided with the ozone monitor has a pass-band width that is about 0.9% of the center wavelength, and the center wavelength varies from 7 to 14μm with 180° rotation of the wheel. This filter wheel is used as the monochromator element in this instrument. Relay optics refocus the energy on the mercury-doped germanium infrared detector that is cooled with a mechanical refrigerator.** The output of this detector, called the main detector, is processed to provide the infrared spectrum and/or readout of absorbing material in the beam.

A dichroic mirror in the beam ahead of the filter wheel reflects a band of wavelengths from 2.8 to 4.3 μm to an uncooled indium arsenide infrared detector. This auxiliary detector is used to provide frequency and phase information about the chopped radiant power from the distant transmitter. In addition, the auxiliary detector can be used to obtain atmospheric transmission information in its wavelength band. If atmospheric scintillation were a problem and if there is an instantaneous correlation between the received signal in the main and auxiliary channels, then the signal in the main channel could be normalized with the signal in the auxiliary channel to reduce the effects of scintillation. Figure 2-2 shows a photograph of the receiver unit with its cover removed.

---

*Made by Optical Coating Laboratory, Inc., Santa Rosa, Calif. 95403; V. L. Yen, Optical Spectra, May/June 1969, pp. 78-84.

**Malaker Corporation, High Bridge, N. J. 08829.

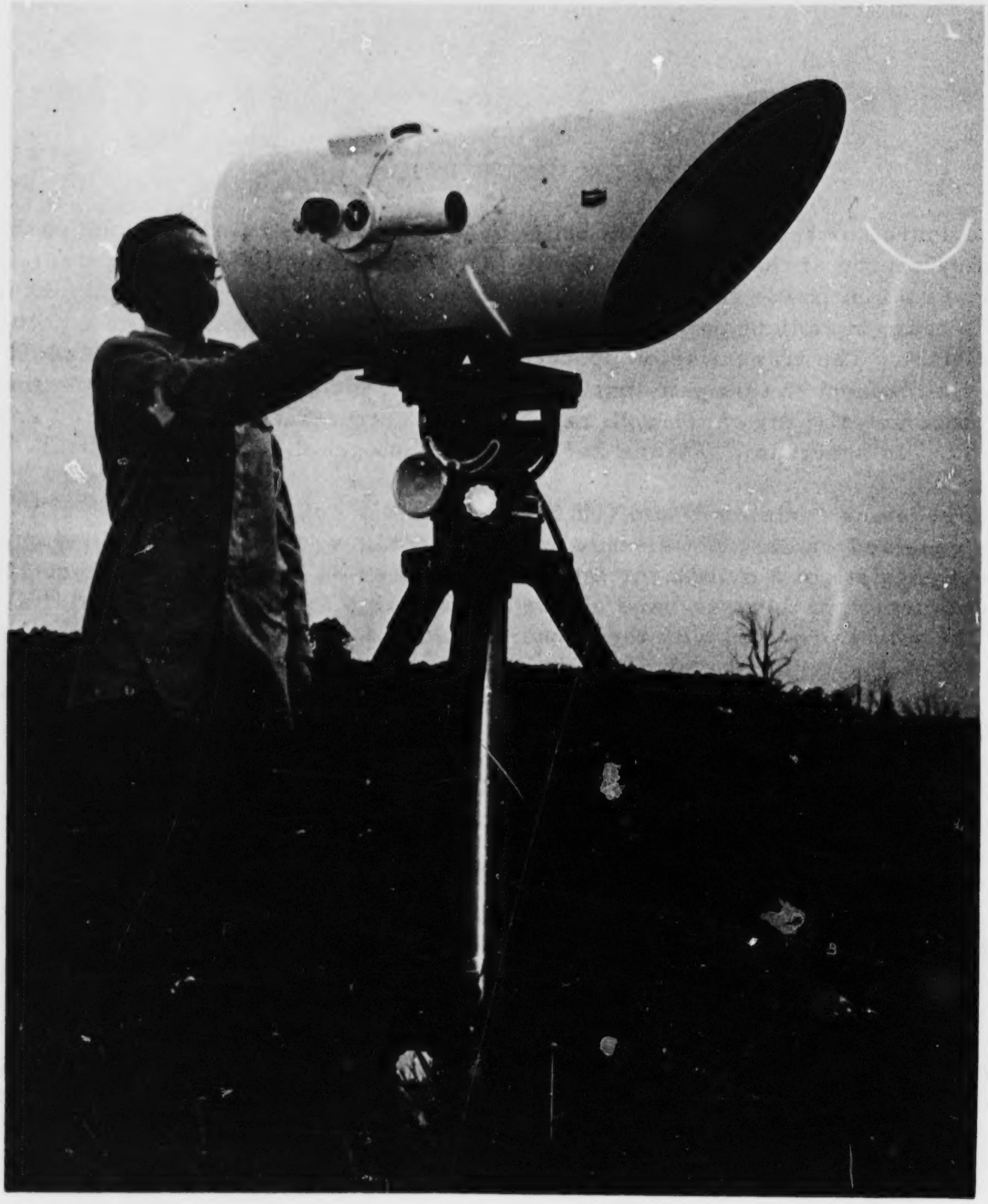
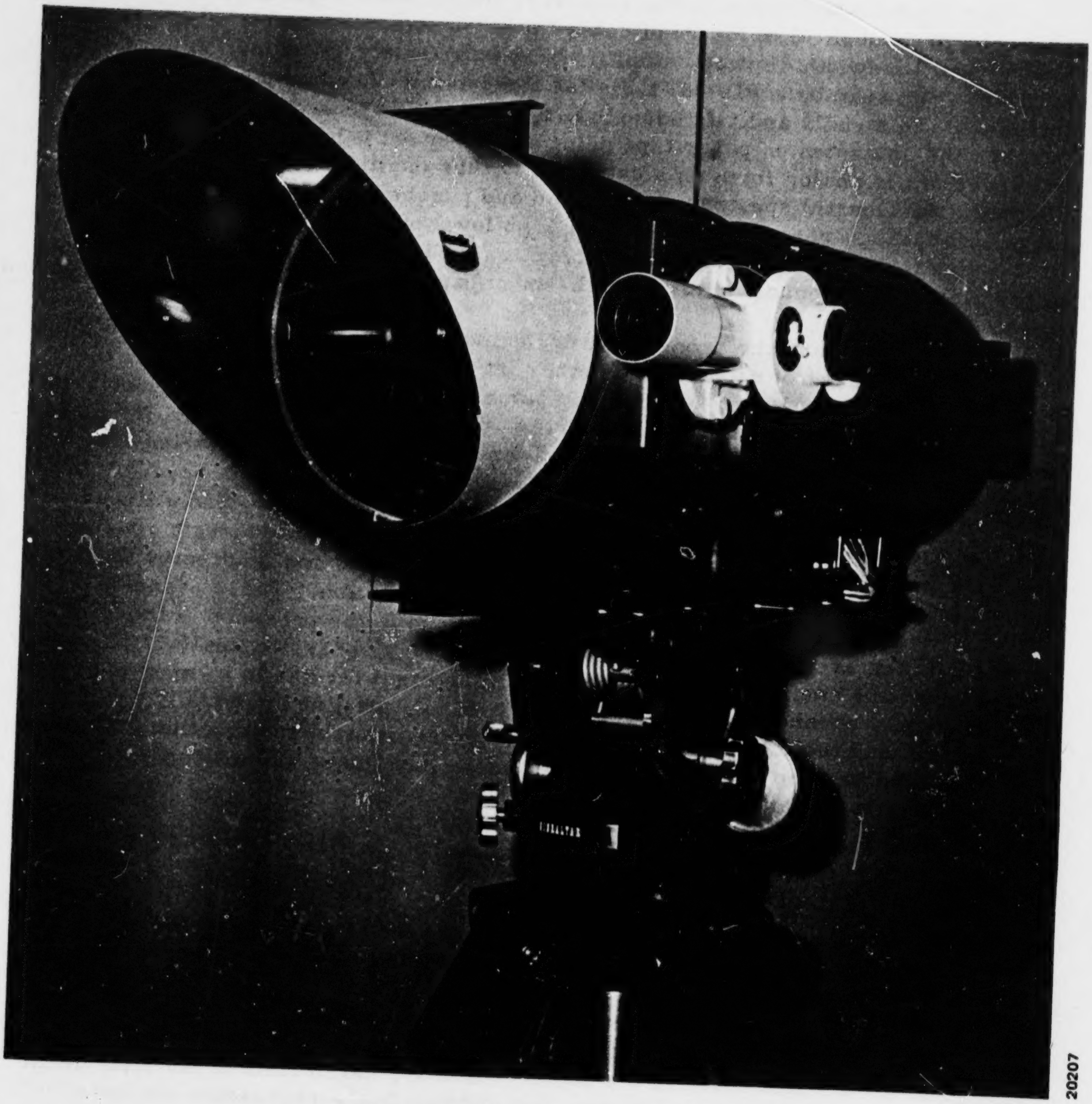


Figure 2-1 Transmitter Unit

NOT REPRODUCIBLE



8378-11

20207

Figure 2-2 Receiver Unit

NOT REPRODUCIBLE

After preamplification in the receiver, the detector signals in the two channels go through 15 m (50 ft) of cable to the electronics console where they are further bandwidth-limited, amplified, synchronously rectified, integrated, digitized, and read by a PDP-8/L digital computer.* The computer further integrates the signals and, if requested, types out the spectrum on a Teletype, punches the spectrum on paper tape using a high-speed punch, and/or displays the spectrum in analog form on a cathode ray tube oscilloscope. Typically, a 50-point (wavelength) spectrum is obtained and punched every nine seconds. The digital output tape permits an extremely high level of flexibility in subsequently processing the spectra in an off-line computer. Figure 2-3 shows a photograph of the electronics console before a high-speed paper tape punch/reader was installed.

The computer in the ozone monitor, using a base-line method, can also calculate the amount of ozone and/or other infrared absorbing materials in the beam. To do this, a larger off-line computer is first used to analyze spectra taken with the ozone monitor. Wavelengths are selected that are useful for measuring the ozone concentration, while simultaneously rejecting interferences. A statistical analysis based on stepwise linear multiple regression is used.** In brief, linear regression analysis uses a least-squares method to find a linear equation that predicts the amount of ozone present from the wavelength readings. Stepwise regression analysis adds promising wavelengths and ignores or deletes unpromising channels to reduce the error of the prediction. Those channels are selected which are well-suited for measuring ozone in the presence of those interferences which are actually present in the spectra. Regression analysis also determines weighting coefficients for each selected channel for use in forming a linear combination of channel readings. The result of this off-line analysis is a list of the wavelengths and their coefficients to be used in the ozone determination. This list is then loaded into the PDP-8/L computer where the linear summation and the ozone concentration are computed.

$$y = c_1 x_1 + c_2 x_2 + c_3 x_3 + \ldots \approx CL\overline{x}$$

where y is the regression sum, the x's are the spectral readings at the selected wavelengths, the c's are the corresponding coefficients, C is the average concentration of ozone in the beam, L is the optical path length, and $\overline{x}$ is the mean of the x's. The ozone monitor computer uses a digital low pass filter to smooth the calculated amount of ozone over several spectra and then computes and prints out the average ozone concentration in the beam. Initially, calibration of the instrument was based on available ozone spectra, but ultimately the regression analysis and ozone calibration could be based on independent measurements of ozone concentration obtained by other methods during the calibration spectral scans.

---

*Digital Equipment Corporation, Maynard, Mass. 01754.

**N. R. Draper and H. Smith, Applied Regression Analysis, New York, John Wiley & Sons, 1966.

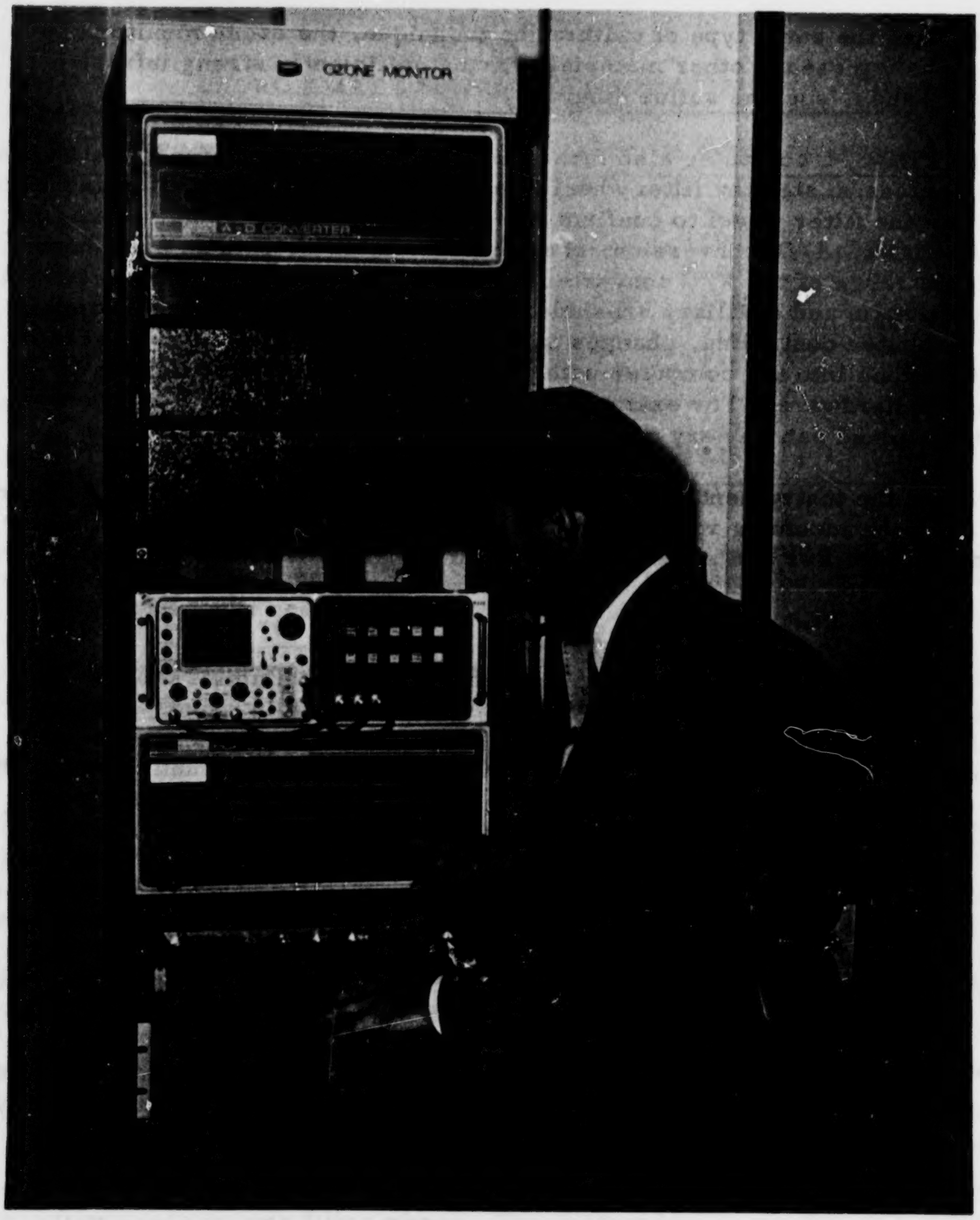


Figure 2-3 Electronics Console

NOT REPRODUCIBLE

By using the same type of calibration technique, the ozone monitor can simultaneously measure other materials having sufficiently strong infrared absorption bands, such as sulfur dioxide.

The PDP-8/L computer also furnishes instrument control functions such as providing pulses to step the filter wheel to a new desired position, checking a feedback signal from the filter wheel to confirm the accuracy of the stepping, calling for analog-to-digital (A/D) conversion, changing the amplifier gain so as to best use the dynamic range of the A/D converter, and controlling the multiplexer to switch between the main and auxiliary channels. Because the instrument operation is largely computer controlled, changes in operation are readily made by reading new instructions into the computer with a punched paper tape rather than by changing the hardware. For example, the number and locations of the wavelengths that are examined can be very easily changed to meet different conditions.

To use the instrument as a passive radiometer, a chopper in the receiver is used to chop the incoming radiant power. Frequency and phase information for the synchronous rectifier and system timing is also derived from the chopper.

2.1 TRANSMITTER

The source is a silicon carbide helix mounted on an alumina tube.* The electrically heated region is 3/8 in. in diameter and 1 1/8-in. long. It takes a nominal 200 W of electrical power at 80 V. The source is placed in a cavity in a refractory material. A stream of cooling air is blown at the mounting end of the source and around the outside of the source enclosure to ensure that the rest of the transmitter unit is not appreciably heated. The source power supply contains silicon controlled rectifiers and has a silicon cell mounted on the secondary mirror of the optical system. This silicon cell provides optical feedback to keep the source temperature constant. The source is designed to be run in the temperature range of 1150 to 1320°C. Table 2-1 shows the approximate source temperature (as measured with an optical pyrometer**) as a function of the control setting on the source controller.

The ozone monitor was delivered with a controller setting of 1.75. A 3600-rpm synchronous motor drives the eight-bladed chopper in front of the source cavity. This motor is air cooled with a fan.

---

*Obtainable from The Carborundum Company, P.O. Box 339, Niagara Falls, N.Y. 14302 as a Gas Igniter, Part No. E-2055-2.

**Mikael Bramson, Infrared Radiation, New York, Plenum Press, 1968, pp. 155-164.

TABLE 2-1

APPROXIMATE SOURCE TEMPERATURE

Controller Setting	Source Temperature (°C)
0.50	960
0.75	1100
0.90	1140
1.00	1165
1.25	1210
1.50	1235
1.75	1265
2.00	1295
2.25	1325

The source is at the focus of a Dall-Kirkham optical system with a primary mirror diameter of 33 cm and 62.2-cm system focal length. The optical system is focused by rotating the secondary mirror.

The transmitter is mounted on a sturdy tripod with adjustments for height, azimuth, and elevation.

2.2 RECEIVER

The receiver optics include a Dall-Kirkham optical system with a primary mirror diameter of 28 cm, a secondary mirror diameter of 15 cm, and a system focal length of 40 cm. The specified blur circle diameter is less than 0.25 mm. Figure 2-4 shows the transmittance and reflectance curves of the dichroic beam splitter at a 45° angle of incidence. The short-wavelength radiation is focused through a filter onto the room temperature indium arsenide photovoltaic auxiliary infrared detector. Figure 2-4 also shows the spectrum of the filter. The indium arsenide infrared detector has a 1-mm-diameter area, a blackbody D* of 3.15 x 10^8 cm-Hz$^{1/2}$/W and a resistance of 56 ohms. The spectral response of indium arsenide is very low beyond 3.9 μm.

The long-wavelength radiation is focused on the filter wheel. The rear of the filter wheel is the wavelength-selecting side. Figures 2-5 and 2-6 show the manufacturer's data on this filter wheel. The filter wheel is driven by a pulse-actuated stepping motor. Table 2-2 gives the center wavelengths corresponding

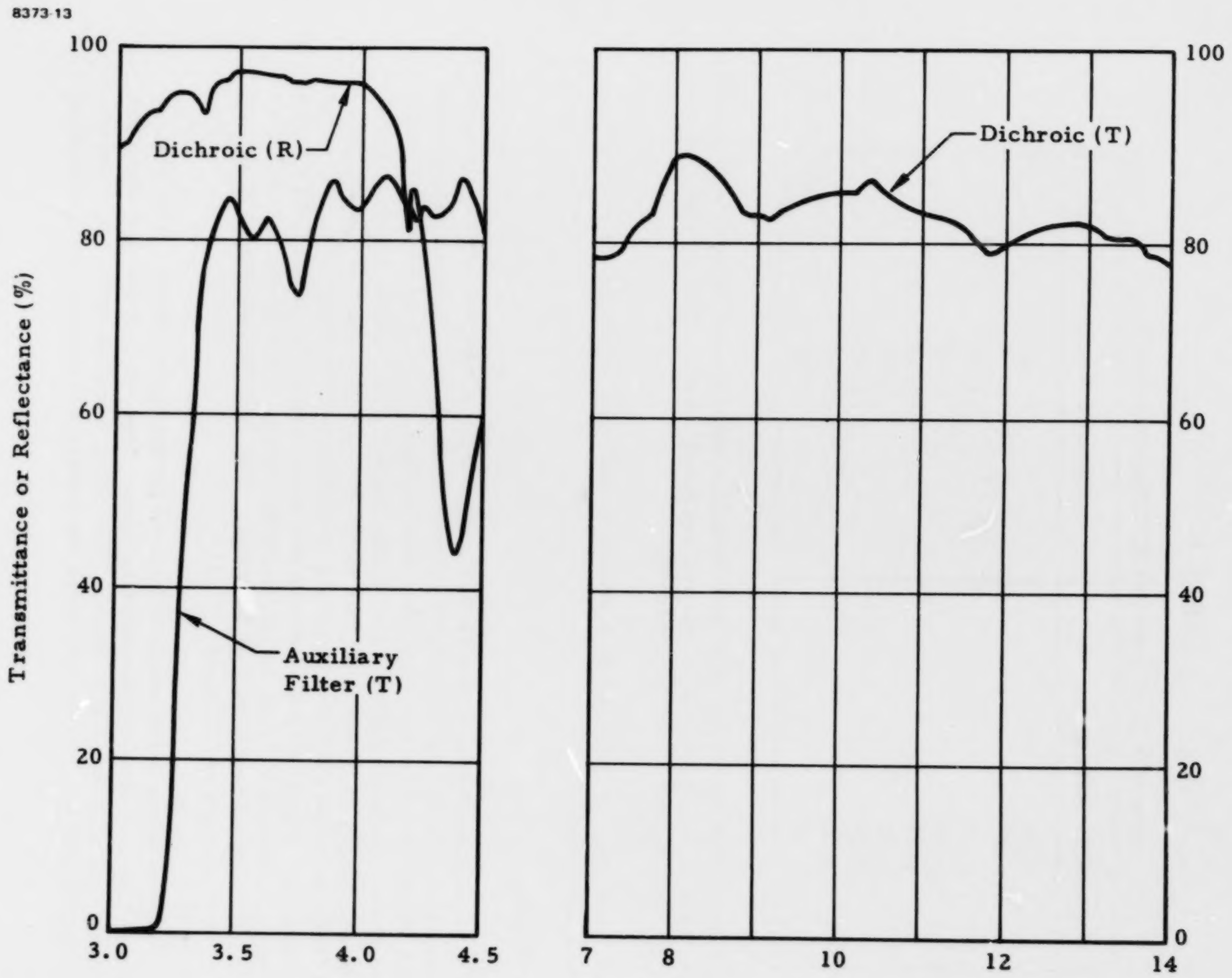


Figure 2-4 Transmittance and Reflectance of Beam Splitter and Auxiliary Filter

```
           SPECTRAL DATA REPORT   CIRCULAR VARIABLE FILTER


CUSTOMER       BENDIX
PURCHASE ORDER NO.        K-4140
OCLI WORK ORDER NO.        14-5738-761
BATCH NO.         12M-1-62-299
ITEM I.D.         1



------------------------------------------------------------------


  THETA     LAMDA θ     PCT HBW      VHBW      THETA'    LAMDA'θ  DEVIATION

    0.       6.9767     0.8351     0.0329         0.      6.9018     1.0858
   30.       7.9818     0.9707     0.1026        30.      8.0682    -1.0702
   60.       9.1884     0.9237     0.0557        60.      9.2345    -0.4987
   90.      10.4005     0.8689     0.0209        90.     10.4009    -0.0030
  120.      11.6265     0.8536     0.0143       120.     11.5672     0.5130
  150.      12.7917     0.8236     0.0444       150.     12.7336     0.4563
  180.      13.8434     0.7801     0.0878       180.     13.8999    -0.4064
         AVERAGE HBW = 0.8680




COLUMN EXPLANATIONS

   THETA = ANGULAR POSITION ON FILTER IN DEGREES
 LAMDA θ = BANDPASS CENTER WAVELENGTH IN MICRONS, AT POSITION THETA
     HBW = BANDPASS WIDTH AT THE HALFPOWER POINTS IN PERCENT OF LAMDA
    VHBW =(AVERAGE HBW)- HBW
  THETA' = ANGULAR POSITION FOR PURPOSES OF BEST FIT STRAIGHT LINE
 LAMDA'θ = CENTER WAVELENGTH VALUES FOR BEST FIT STRAIGHT LINE,
           LAMDA'θ = K * THETA'
DEVIATION = (LAMDA θ - LAMDA'θ * 100/LAMDA θ
```

8378-26

Figure 2-5 Filter Wheel Data Report

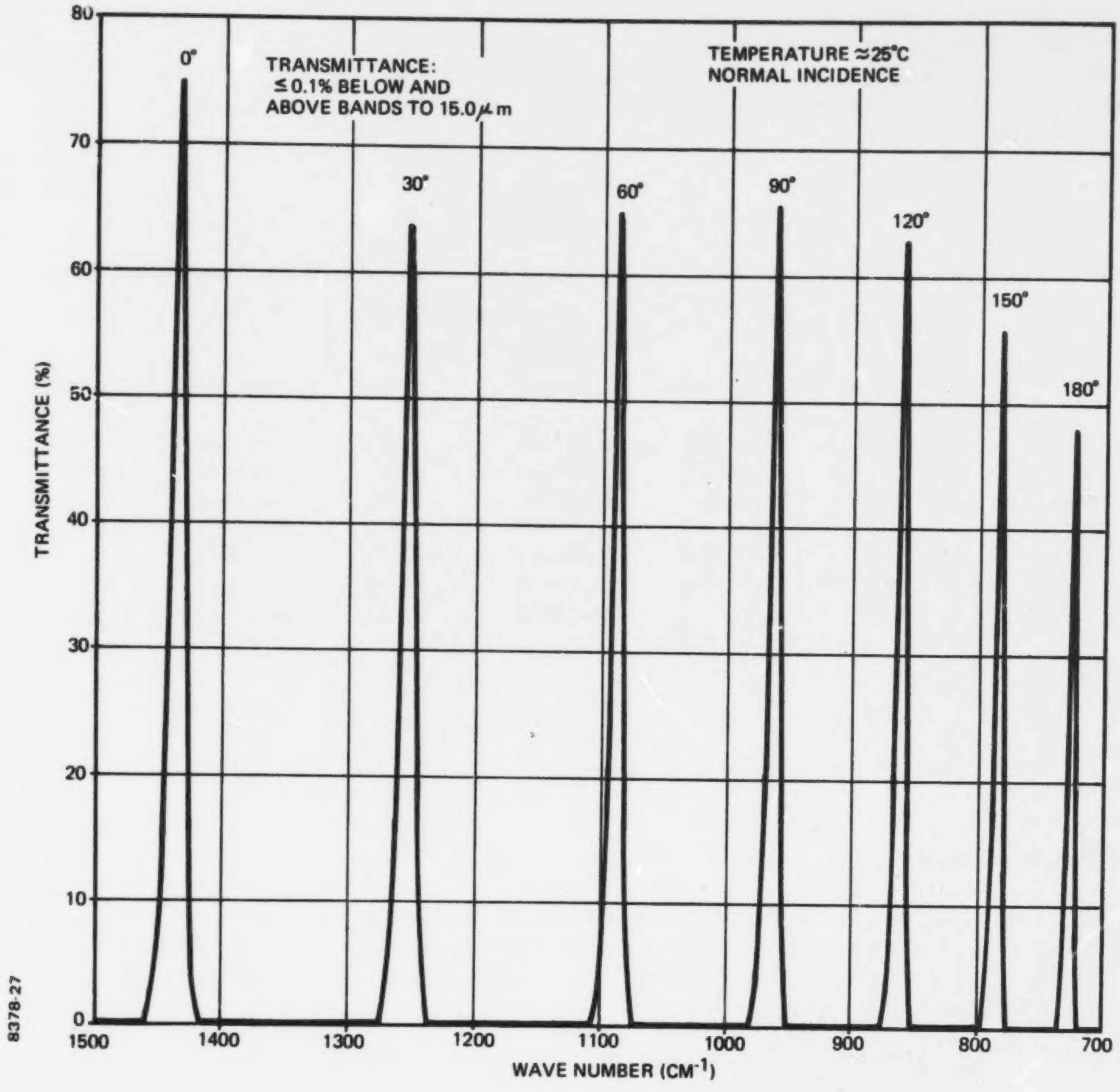


Figure 2-6 Filter Wheel Transmittance

TABLE 2-2

8378-A

FILTER WHEEL WAVELENGTHS (Page 1 of 2)

FWPOS	OCTAL	CHAN	MICRON
0	0		6.97
1	1		6.98
2	2		7.00
3	3		7.01
4	4		7.03
5	5		7.04
6	6		7.06
7	7		7.07
8	10		7.08
9	11	1	7.10
10	12		7.11
11	13		7.13
12	14		7.14
13	15		7.16
14	16		7.17
15	17		7.19
16	20		7.20
17	21		7.22
18	22		7.23
19	23	2	7.25
20	24		7.26
21	25		7.28
22	26		7.29
23	27		7.31
24	30		7.32
25	31		7.34
26	32		7.35
27	33		7.37
28	34		7.38
29	35	3	7.40
30	36		7.42
31	37		7.43
32	40		7.45
33	41		7.46
34	42		7.48
35	43		7.49
36	44		7.51
37	45		7.52
38	46		7.54
39	47	4	7.56
40	50		7.57
41	51		7.59
42	52		7.60
43	53		7.62
44	54		7.64
45	55		7.65
46	56		7.67
47	57		7.68
48	60	5	7.70
49	61		7.72
50	62		7.73
51	63		7.75
52	64		7.76
53	65		7.78
54	66		7.80
55	67		7.81
56	70		7.83
57	71	6	7.85
58	72		7.86
59	73		7.88
60	74		7.89
61	75		7.91
62	76		7.93
63	77		7.94
64	100		7.96
65	101		7.98
66	102	7	7.99
67	103		8.01
68	104		8.03
69	105		8.04
70	106		8.06
71	107		8.08
72	110		8.09
73	111		8.11
74	112		8.13
75	113	8	8.14
76	114		8.16
77	115		8.18
78	116		8.20
79	117		8.21
80	120		8.23
81	121		8.25
82	122		8.26
83	123		8.28
84	124	9	8.30
85	125		8.32
86	126		8.33
87	127		8.35
88	130		8.37
89	131		8.38
90	132		8.40
91	133		8.42
92	134		8.44
93	135	10	8.45
94	136		8.47
95	137		8.49
96	140		8.51
97	141		8.52
98	142		8.54
99	143		8.56
100	144		8.58
101	145	11	8.59
102	146		8.61
103	147		8.63
104	150		8.65
105	151		8.66
106	152		8.68
107	153		8.70
108	154		8.72
109	155		8.73
110	156	12	8.75
111	157		8.77
112	160		8.79
113	161		8.80
114	162		8.82
115	163		8.84
116	164		8.86
117	165		8.88
118	166	13	8.89
119	167		8.91
120	170		8.93
121	171		8.95
122	172		8.97
123	173		8.98
124	174	14	9.00
125	175		9.02
126	176		9.04
127	177		9.06
128	200		9.07
129	201		9.09
130	202	15	9.11
131	203		9.13
132	204		9.15
133	205		9.16
134	206		9.18
135	207	16	9.20
136	210		9.22
137	211		9.24
138	212		9.25
139	213		9.27
140	214		9.29
141	215	17	9.31
142	216		9.33
143	217		9.35
144	220		9.36
145	221		9.38
146	222	18	9.40
147	223		9.42
148	224		9.44
149	225		9.45
150	226		9.47
151	227	19	9.49
152	230		9.51
153	231		9.53
154	232		9.55
155	233		9.56
156	234		9.58
157	235	20	9.60
158	236		9.62
159	237		9.64
160	240		9.66
161	241		9.68
162	242	21	9.69
163	243		9.71
164	244		9.73
165	245		9.75
166	246		9.77
167	247		9.79
168	250	22	9.80
169	251		9.82
170	252		9.84
171	253		9.86
172	254		9.88
173	255	23	9.90
174	256		9.92
175	257		9.93
176	260		9.95
177	261		9.97
178	262		9.99
179	263	24	10.01
180	264		10.03
181	265		10.05
182	266		10.06
183	267		10.08
184	270	25	10.10
185	271		10.12
186	272		10.14
187	273		10.16
188	274		10.18
189	275	26	10.19
190	276		10.21
191	277		10.23
192	300		10.25
193	301		10.27
194	302		10.29
195	303	27	10.31
196	304		10.32
197	305		10.34
198	306		10.36
199	307		10.38
200	310	28	10.40
201	311		10.42
202	312		10.44
203	313		10.45
204	314		10.47
205	315	29	10.49
206	316		10.51
207	317		10.53
208	320		10.55
209	321		10.57
210	322		10.58
211	323		10.60
212	324		10.62
213	325	30	10.64
214	326		10.66
215	327		10.68
216	330		10.70
217	331		10.71
218	332		10.73
219	333		10.75
220	334		10.77
221	335		10.79
222	336	31	10.81
223	337		10.83
224	340		10.84
225	341		10.86
226	342		10.88
227	343		10.90
228	344		10.92
229	345		10.94
230	346	32	10.96
231	347		10.97
232	350		10.99
233	351		11.01
234	352		11.03
235	353		11.05
236	354		11.07
237	355		11.09
238	356	33	11.10
239	357		11.12
240	360		11.14
241	361		11.16
242	362		11.18
243	363		11.20
244	364		11.21
245	365		11.23
246	366	34	11.25
247	367		11.27

TABLE 2-2

8378-A

FILTER WHEEL WAVELENGTHS (Page 2 of 2)

FWPUS	OCTAL	CHAN	MICRON
248	370		11.29
249	371		11.31
250	372		11.32
251	373		11.34
252	374		11.36
253	375		11.38
254	376	35	11.40
255	377		11.42
256	400		11.43
257	401		11.45
258	402		11.47
259	403		11.49
260	404		11.51
261	405		11.53
262	406	36	11.54
263	407		11.56
264	410		11.58
265	411		11.60
266	412		11.62
267	413		11.64
268	414		11.65
269	415		11.67
270	416		11.69
271	417	37	11.71
272	420		11.73
273	421		11.74
274	422		11.76
275	423		11.78
276	424		11.80
277	425		11.82
278	426		11.83
279	427	38	11.85
280	430		11.87
281	431		11.89
282	432		11.91
283	433		11.92
284	434		11.94
285	435		11.96
286	436		11.98
287	437	39	12.00
288	440		12.01
289	441		12.03
290	442		12.05
291	443		12.07
292	444		12.08
293	445		12.10
294	446		12.12
295	447		12.14
296	450	40	12.15
297	451		12.17
298	452		12.19
299	453		12.21
300	454		12.23
301	455		12.24
302	456		12.26
303	457		12.28
304	460	41	12.30
305	461		12.31
306	462		12.33
307	463		12.35
308	464		12.36
309	465		12.38
310	466		12.40
311	467		12.42
312	470		12.43
313	471	42	12.45
314	472		12.47
315	473		12.49
316	474		12.50
317	475		12.52
318	476		12.54
319	477		12.55
320	500		12.57
321	501		12.59
322	502	43	12.61
323	503		12.62
324	504		12.64
325	505		12.66
326	506		12.67
327	507		12.69
328	510		12.71
329	511		12.72
330	512	44	12.74
331	513		12.76
332	514		12.78
333	515		12.79
334	516		12.81
335	517		12.83
336	520		12.84
337	521		12.86
338	522		12.88
339	523	45	12.89
340	524		12.91
341	525		12.93
342	526		12.94
343	527		12.96
344	530		12.97
345	531		12.99
346	532		13.01
347	533		13.02
348	534		13.04
349	535	46	13.06
350	536		13.07
351	537		13.09
352	540		13.10
353	541		13.12
354	542		13.14
355	543		13.15
356	544		13.17
357	545		13.19
358	546	47	13.20
359	547		13.22
360	550		13.23
361	551		13.25
362	552		13.26
363	553		13.28
364	554		13.30
365	555		13.31
366	556		13.33
367	557	48	13.34
368	560		13.36
369	561		13.37
370	562		13.39
371	563		13.41
372	564		13.42
373	565		13.44
374	566		13.45
375	567		13.47
376	570		13.48
377	571	49	13.50
378	572		13.51
379	573		13.53
380	574		13.54
381	575		13.56
382	576		13.57
383	577		13.59
384	600		13.60
385	601		13.62
386	602		13.63
387	603	50	13.65
388	604		13.66
389	605		13.68
390	606		13.69
391	607		13.71
392	610		13.72
393	611		13.74
394	612		13.75
395	613		13.77
396	614		13.78
397	615		13.80
398	616		13.81
399	617		13.83

to each filter wheel position (FWPOS). The octal equivalent of each filter wheel position is also given. (The PDP-8/L computer accepts the filter wheel position list in octal.) Also shown are the present channel locations (CHAN). The wavelength information in Table 2-2 was obtained by a least-square fit of a cubic equation to the data in Figure 2-6. The filter wheel reference position (FWREF), which is the filter wheel position where the computer recognizes the light shining through the narrow slit in the rim of the filter wheel, was found to be $(373)_8$ or 11.34 μm. The spectral resolution of the filter wheel mounted in the ozone monitor was not measured, but it will be somewhat larger than shown in Figures 2-5 and 2-6. This is true because of the range in the angle of incidence upon the filter wheel due to the f/1.5 optical system and because of the non-zero size of the source image on the filter wheel, which can be as large as 1 mm—although in the active mode at long ranges it will be less, perhaps 0.25 mm.

Cemented to the outside of the filter wheel is an aluminum rim and flange. The flange normally does not permit light from a small incandescent bulb to reach a phototransistor on the other side of the flange. But a narrow slot in the flange allows the light to reach the phototransistor for a small range of filter wheel angle when the filter wheel is transmitting in the vicinity of 11.34 μm. This is used as a check by the computer to assure that there have been no mistakes in stepping the filter wheel. If a mistake is found and if the computer switch registers are properly set, the spectrum is rejected, the instrument spins the filter wheel to reacquire the light, and the instrument proceeds to take a new spectrum.

In front of the filter wheel is a 16-blade chopper. When the ozone monitor is used in the active mode, the chopper positioned with a locking screw so that it does not block the beam. When the instrument is used in the passive mode, the locking screw is withdrawn and the chopper motor is turned on. The synchronous chopper motor turns the chopper at 1800 rpm. The blades are deeply grooved and painted black so as to simulate a blackbody at ambient air temperature. An incandescent light is on one side of the chopper and a phototransistor is on the other side. The light and phototransistor can be mechanically phased relative to the chopper, and are used to generate timing pulses when the instrument is in the passive mode.

An aperture close to the back of the filter wheel rejects stray light that might cause spurious signals. Two pierced paraboloidal mirrors reimage the radiant power from the back of the filter wheel through a window onto the main infrared detector with unit magnification. A circular disk between the two mirrors prevents the detector from receiving chopped radiant power that does not come from the mirrors and prevents a possible spurious signal when in the passive mode.

The disk does not obscure any desired energy as it corresponds to the central blocked region in the hollow cone of light from the Cassegrainian-type collector optics.

The mercury-doped germanium infrared detector is mounted on the cold surface of the refrigerator. It is enclosed in a vacuum jacket to prevent convective heat input. A 1-mm-thick IRTRAN-2 window serves as the entrance to the vacuum jacket.

Mounted on the vacuum jacket is a three-position detented wheel. One position leaves the beam open, another blocks the beam, and the third position inserts a 0.0012-in. thick sheet of polystyrene in the beam. In normal use, the beam is unblocked; the other two positions are useful for test and wavelength calibration purposes, especially in the passive mode. (Filters should be inserted in the beam between the chopper and the infrared detector, if the infrared radiance of the filter is not to be chopped.)

The main infrared detector has a cold collar around it to restrict its field of view to about 30° full angle. It has a 1-mm-diameter sensitive area and was measured to have a blackbody D* (500 K, 450 Hz) of 3.6×10^9 cm - $\mathrm{Hz}^{1/2}$/W and a cold resistance of about 700 kΩ. It is operated at a constant voltage bias of 5 V that is current-limited at 88μ A to prevent damage to the detector when it is warm. The preamplifier and bias circuit has low impedance so that the detector responsivity does not change with varying photon flux, such as can be caused by varying ambient temperatures or rotation of the filter wheel.

The refrigerator is mounted in a large cylinder that can be accurately positioned in three dimensions by turning threaded bolts and the adjustment can then be securely fastened.

2.3 ELECTRONICS

2.3.1 Source

Power is supplied from the 115-VAC, 60-Hz mains and used to operate the synchronous chopper motor and the source power supply. The source power supply uses optical feedback to maintain the source at constant temperature.

2.3.2 Receiver

Spectral multiplexing is accomplished in the receiver by advancing a filter wheel from one spectral region to the next with a stepper motor. Control signals are generated in the console by the PDP-8/L computer, and the stepper motor has the capability of moving forward or reversing at any speed up to 1000 steps/second.

One filter wheel position is monitored by a photodiode, lamp, and amplifier combination and transmitted to the computer. For other positions, the computer registers the number of pulse signals sent to the stepper motor and thus keeps count of the channel position of the filter wheel.

The main preamplifier also provides detector bias. It is a constant voltage source that is, however, current-limited to avoid burning out the infrared detector when the detector is at room temperature and has a low resistance.

2. 3. 3 Central Control Electronics

The central electronics consist of interface electronics, computer, oscilloscope, and required power supplies. The following paragraphs explain the function of each block and give typical schematics.

2. 3. 3. 1 Automatic Range Control Amplifiers

The detected signals from the receivers are accepted at the central electronics by the automatic range control (ARC) amplifiers. Each amplifier, as shown in Figure 2-7, consists of three integrated differential amplifiers. Gain can be controlled by the field effect transistor switches associated with the first two amplifiers as shown and can take on the following values: 1, 2, 4, 8, 16, 32, 64, or 128, developed by a three-bit binary code from the computer. The third amplifier is connected as a unity gain inverter.

2. 3. 3. 2 Synchronous Detectors, Integrators, and Multiplexer

Sunchronous detection is accomplished by the action of the switches S_1, S_2, S_3, and S_4 (as shown in Figure 2-8) on the split-phase signals from the ARC amplifiers. The control signals for the switches are produced by the phase-locked synchronization circuitry to be described in Section 2. 3. 3. 3. The integrals of the detected signals are produced by amplifiers A1 and A2. Switches S5 and S6, under the control of the computer, reset each integral to zero after each digitized reading is taken.

Switches S7 and S8, also under control of the computer, select either the main or the auxiliary integral for delivery to amplifier A3, which offsets the selected signal to the minus five volt reference level required by the A/D converter.

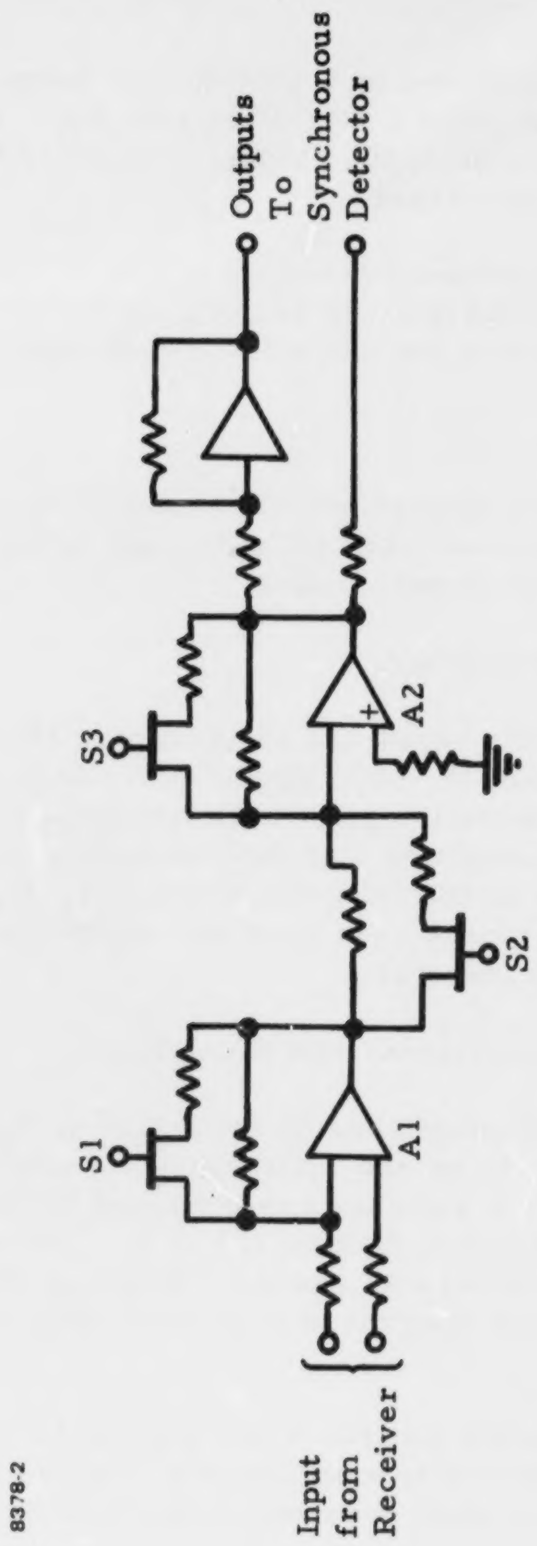


Figure 2-7 Automatic Range Control Amplifier

8378-4

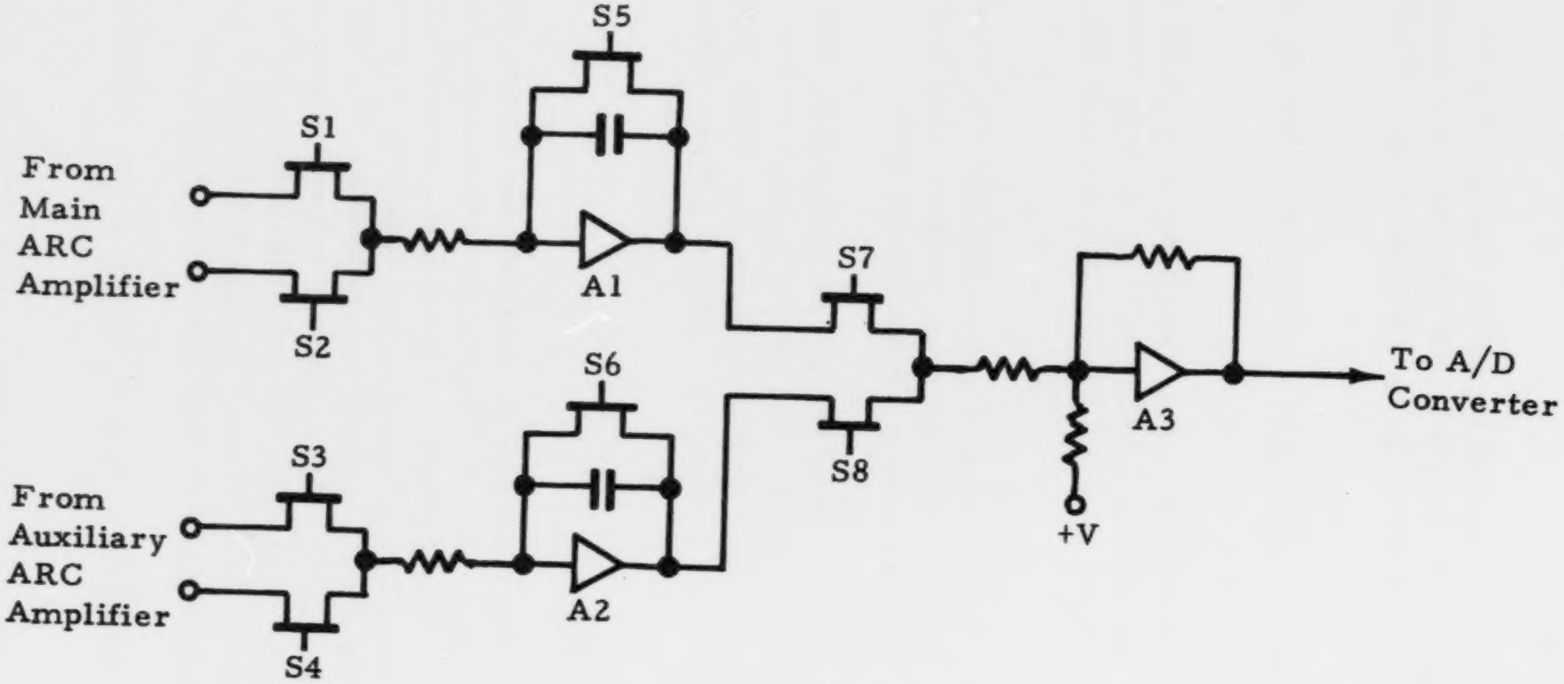


Figure 2-8 Synchronous Detectors, Integrators, and Multiplexer

2.3.3.3 Synchronization Circuitry

Timing signals are derived from either of the two mechanical choppers in the system. When the active mode is selected, the auxiliary signal serves as the phase reference; in the passive mode, a signal from the local chopper in the receiver is used.

The selected signal is used as the phase reference in the phase-locked control loop illustrated in Figure 2-9.

The voltage-controlled oscillator shown generates a 3840-Hz pulse train which is successively divided by two to produce the 480-Hz signals needed for the synchronous detection of the main and auxiliary signals and the 480-Hz interrupts to the PDP-8/L.

A 480-Hz signal is also used to detect synchronously the selected phase reference signal as shown. The synchronous detector output, after appropriate filtering, controls the oscillator frequency to maintain phase lock.

In the event of the disappearance of the phase reference, which can occur as a result of mispointing in the active mode, the level detector causes the selection of the 60-Hz power frequency for use as a timing reference. This procedure maintains system timing at the correct frequency until the proper phase reference signal is restored.

2.3.3.4 Computer Interface Logic

This section of the central electronics provides the signal conditioning, level translations, and switching functions necessary for communication between the computer and the remainder of the system. Signal data, synchronizing pulses (filter wheel and chopper reference), and discrete data from the software selection switches on the front panel are received, properly conditioned, and made available to the computer under program control. All computer outputs (except hard copy which is interfaced in the Teletype unit) pass into this subsystem and are conditioned to provide the oscilloscope display, gain control signals for the ARC amplifiers, integrator dump signal, and filter wheel forward and reverse signals.

These functions, block-diagrammed in Figure 2-10, are accomplished in the following manner:

1. Signal data input from the receiver is processed by the integrate and dump technique. The dump is controlled by a device selector

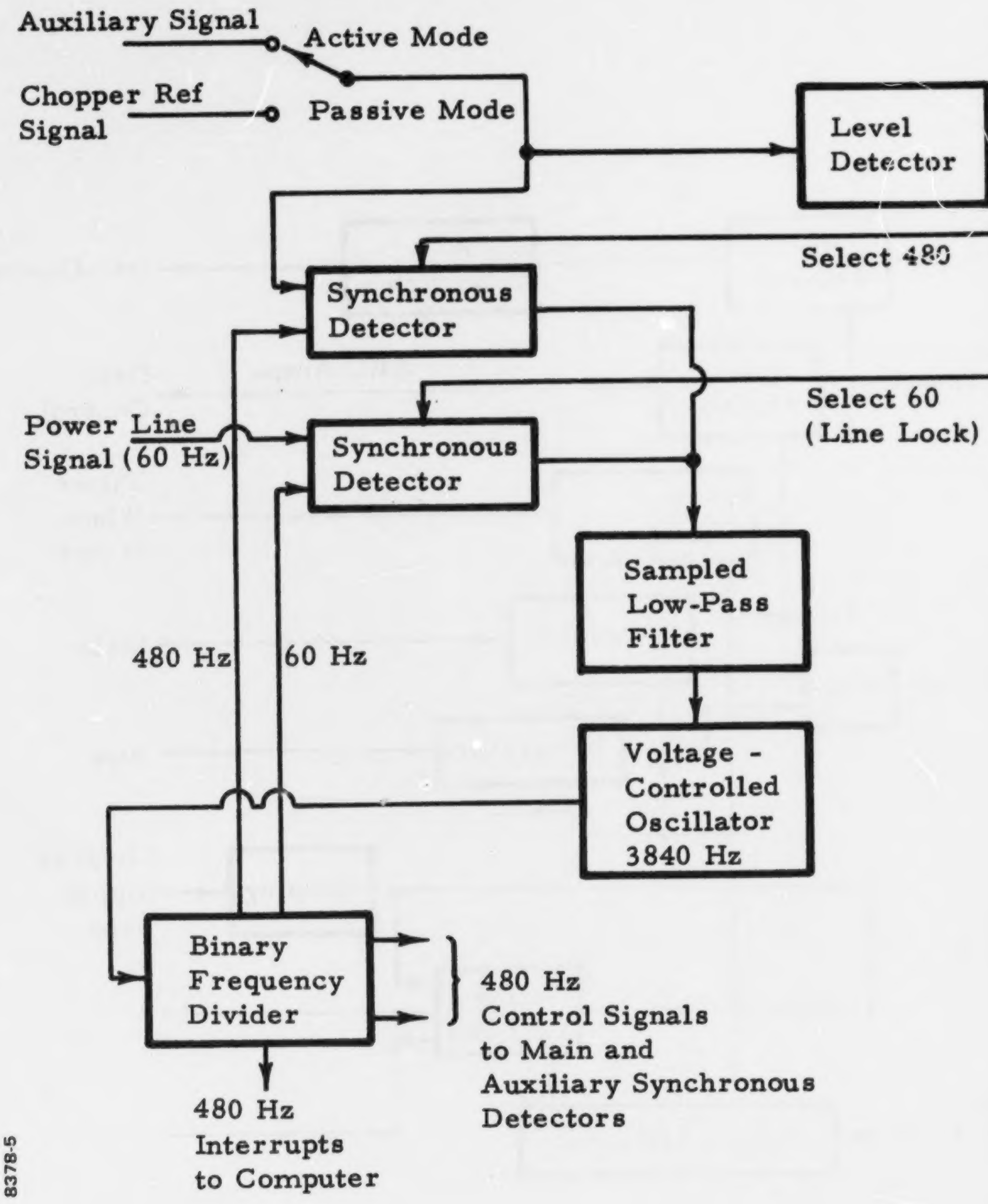


Figure 2-9 Synchronization Block Diagram

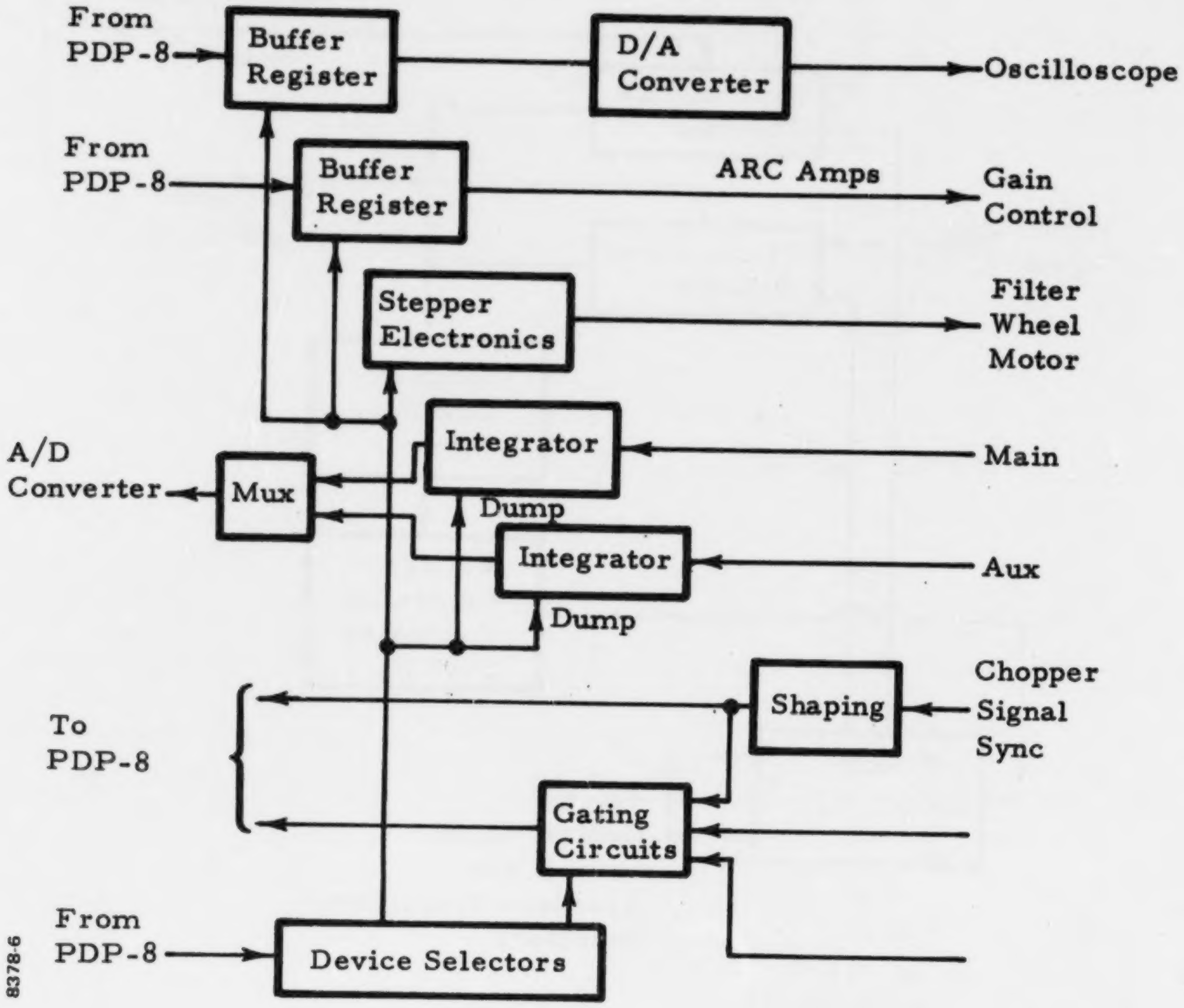


Figure 2-10 Computer Interface Logic

circuit which provides a pulse during the execution of the appropriate computer instruction. The multiplexer selects an integrator whose output is digitized by the A/D converter.

2. The synchronizing signals and discrete program control data are entered into the computer through gating circuits under control of device selectors. The chopper sync pulse is reshaped to make it compatible with the requirements of the computer.

3. The oscilloscope display data are passed from computer storage into a buffer register in the interface under control of a device selector. The D/A conversion is performed in the unit on the contents of the register and the resultant voltage is sent to the oscilloscope display unit.

4. The three bits of information necessary to set gain levels in the ARC amplifiers likewise are stored in buffer registers. Storage of the stepper motor pulses for filter wheel positioning is not required. These come directly from the appropriate device selector and are lengthened, amplified, and sent to the stepper motor drive module.

2.3.4 Signal Processing

The demodulated signal must be integrated for a period of time sufficient to yield the desired S/N ratio. The integration is accomplished partly by analog and partly by numerical techniques. The analog integration period is 2083 μsec, corresponding to one chopping cycle of the 480-Hz chopping frequency. At the end of the analog integration period, the analog integral is digitized and the integrator is then issued a reset command by the computer. While the next analog integration is in process, the computer adds the latest reading to the sum of earlier readings from the same spectral channel. The total integration time is determined by multiplying the analog integration time by the number of terms in the summation, currently 64 (stored in the constant NOCPC), and is easily changed to other values should a larger signal be required for any reason.

The signal processing performed by the computer can be divided into three parts: (1) the basic instrument control and display program, (2) the data gathering program, and (3) the detection processing program.

The chopper reference signal provides the fundamental timing for the instrument control program. The end of a chopping cycle generates an interrupt indicating that a priority task must be performed, via the interface unit, which causes the computer to enter the main interrupt servicing program. The analog input from the interface unit integrator is digitized, and the command is issued to reset the integrator—again via the interface unit. The computer adds the new reading to the accumulated sum of readings and increments the running count of integrator readings by one. If the count has not reached the required number, the main interrupt servicing program is terminated, and the computer executes a display program to be described later. Interrupt programming is required to perform the essential instrument control tasks (e. g., moving the filter wheel) in a timely manner.

If the count of integrator readings has reached the required number, it is reset to zero, and the computer corrects the sum of accumulated readings for the ARC gain level in use and places the sum in a list of sums ordered by spectral channel number. The spectral channel count is then incremented. If the specified count has not been reached, the computer selects a new filter wheel position and initiates filter wheel stepping to the specified wavelength for the next channel. The new wavelength can be any of those available on the wheel, but usually the wavelength assignments to the channels will be ordered to minimize filter wheel stepping time.

The filter wheel stepping rate is varied by the computer to control the angular acceleration and deceleration. The maximum stepping rate of 480 steps/sec is reached in three steps and maintained until the filter wheel is within three steps of its destination. Each step corresponds to a wavelength shift of about 0.0175 μm.

When the filter wheel has been repositioned, the summation process of the digitized readings resumes at the new wavelength.

When a spectral scan has been completed by finishing the summation for the last channel, the computer causes a runback to the first filter wheel position and starts a new spectral scan.

Each time the filter wheel passes the position at which the reference position signal is generated (at 11.34μm), the computer checks for agreement with its own notion of the filter wheel position. If the check fails, the computer will, at the operator's option, either halt or reinitialize the spectral scanning.

The computer, during each complete spectral scan, determines the magnitude of the highest reading obtained and uses this number to establish the most desirable signal gain to be used for the next spectral scan. The desired gain command is sent via the interface unit to the gain control circuits in the amplifier chain.

The oscilloscope provided is driven by the computer with the aid of a D/A converter in the interface unit. The display program sequentially outputs the entire list of summed channel readings available from the last complete spectral scan to the D/A converter, yielding a bar chart display showing the channel readings for each channel in sequence. The entire display is repeated at the 480-Hz chopping rate. Each individual channel is displayed in about 15 μsec, requiring 750 of the available 2083 μsec to display 50 channels.

When a display cycle is completed, the computer returns to any auxiliary calculations with which it may have been engaged at the time of the chopper interrupt.

The auxiliary programs, data gathering, and detection processing, do not require execution in strict synchronism with the 480-Hz chopping signal and, if called for, are executed in the computer's spare time between interrupts.

The user can invoke the data gathering mode by operating the appropriate control switch. The computer will output a complete list of channel readings, each consisting of a four-digit number.

The user can invoke the detection processing mode by operating another switch. In this mode, the computer sums any combination of spectrally derived channel signals, with selectable polarity and variable weighting constants of any desired value, to yield a single output. If desired, the computer can simultaneously evaluate several such equations, each yielding its own output. The number of such equations that can be processed depends on the number of channels in use. For 64 channels, 10 different equations can be concurrently processed to detect the presence of 10 different air pollutants, or 10 different ways of detecting one pollutant, or any other combination. Thus, several pollutants can be detected simultaneously, and each can be evaluated in several ways.

The single output from each equation is displayed as an auxiliary bar chart on the oscilloscope display and is typed out, along with an identifying message, to provide the quantitative information concerning the concentration of the target pollutant or pollutants.

SECTION 3

DISCUSSION OF COMPUTER PROGRAM

The Ozone Monitor is designed to gather and process real-time spectra to allow remote sensing of atmospheric pollutants, which absorb in the infrared spectral region. The accompanying PDP-8/L computer and software are responsible for providing both the control of the instrument and the processing of data.

For each complete spectral scan, a linear combination of the channel readings, called the regression sum, is computed, if called for. The set of coefficients for this equation is different for each pollutant to be measured. The type of spectra gathered can be varied to include anywhere from zero to 64 channels spaced according to the measurement problem. Both the number of channels and the spectral location of the channels can be varied by the user. The optimum choice of these variables is based upon knowledge of the infrared absorption spectra of the individual pollutants and the absorption characteristics of possible interferences.

One method of determining the number of spectral channels, the spectral location of these channels, and the coefficients for each channel is the use of stepwise multiple regression. This is the method used to provide the coefficients provided for the Ozone Monitor when it was delivered. An example of the use of this method is shown in another section of this report. In essence, this method selects channels and coefficients that can predict (in a least-squares sense) the amount of ozone independently stated to be present in each spectrum of a training set. One way of attaining this training set of spectra is to obtain spectra under various atmospheric conditions and to have an independent measurement of the average ozone concentration in the path during the time each spectrum is taken. Another way of attaining this training set is to obtain a number of spectra when the amount of ozone in the beam is independently known to be very small (essentially zero) and then, knowing the absorption coefficients for ozone as a function of wavelength, to modify these spectra to simulate the presence of an arbitrary known amount of ozone. This latter method was used in the regression analysis performed under this contract. Other simpler methods can also be used, such as the selection of channels from inspection of absorption spectra of the target pollutant and possible interferences. In this case, preliminary coefficients can be obtained by simple calculation based on a few spectra obtained by the ozone monitor and refined by trial and error.

The regression sum is divided by the average signal (using all channels to obtain the average). The purpose is to give a quotient that is independent of signal strength and proportional to the product of ozone concentration and path length (or range). This quotient is divided by the range so as to give a result in concentration units ($\mu g/m^3$).

Large amounts of ozone cause sufficiently large absorption at 9.5 and 9.7 μm so that the linear approximation that is used, namely that the absorbance A is proportional to the fractional absorptance α ($A = \alpha/2.3$), no longer holds. For these large amounts of ozone, a calibration curve can be used to obtain the true amount of ozone from the indicated amount. Alternatively, the computer itself can be programmed to calculate the true absorbance, for example, by taking the logarithm of the transmittance τ of the 9.7 μm spectral channel, and then calculating the ozone concentration from the absorbance ($A = -\log \tau$).

The PDP-8/L software provides control of all instrument functions, such as filter wheel positioning, chopper wheel synchronization of the channel processing, data recording, and the outputting of spectral readings and concentration messages. For discussion purposes, the instrument is said to be operating in the data-gathering mode when punched paper tapes containing channel readings are being generated. This output is compatible with the hardware of a larger computer, such as the IBM-360/50 for use in determining optimum detection coefficients or in performing any other analysis requiring digitized spectral channel readings as input. The alternative mode of operation, the detection processing mode, uses the same kind of channel readings to provide for measurement of those pollutants it has been programmed to detect. In either mode, the function of the instrument is to provide a number proportional to the signal in each spectral channel. The discussion of the software will thus follow the internal logic required for instrument control in the gathering of channel readings. Routines specific to either of the two modes of operation will be noted as necessary.

The primary output of the PDP-8/L software is a spectrum or an ordered set of numbers with each proportional to the most recently observed signal in a spectral channel. This ordered set of numbers is the result of a complete spectral scan, each of the readings corresponding to one spectral location in the range from 7 to 14 μm. This set of numbers is considered a single observation. A typical observation might consist of 50 channels uniformly distributed across the spectral range of the instrument. Both the number and the spectral location of channels comprising a single observation are controlled by input options to the PDP-8/L software.

At the completion of each observation, the result is plotted against channel number on an oscilloscope display and is available for use in the detection processing mode if this user option is in effect. During the execution of this option, the system provides information concerning the concentration of pollutants. This information is presented in two ways:

1. The Teletype will print a message identifying the pollutant and will type a number proportional to the average concentration of the gas in the path length between the transmitter and the receiver.
2. A bar proportional to the average concentration of pollutant will appear on the oscilloscope display.

If detection processing is not desired, the system will continue to gather and display spectra while awaiting further instructions from the operator. If, in the process of observation, the operator notes an interesting spectrum, he has the option of printing out on the Teletype a numerical representation of that spectrum. He need merely press the PRINT DATA button on the control panel to exercise this option. The software will sense this request, forego data gathering at the completion of its present scan, and transfer control to the Teletype which prints out a channel-by-channel list of numbers. To keep a log of his observations, the operator has at his disposal an option that enables him to provide an ID number for each observation. To do this, he must press the ID INCREMENT button for a moment and then release it. This will result in the Teletype printing out an ID number labeling the next observation or set of observations.

Operation in the data-gathering mode requires the user to turn on the power to the high speed punch and press the PUNCH DATA button. The software will then output the channel readings to the punch at the completion of each spectral scan. The ID option can also be used here to label observations. Experience indicates that it is desirable to record supplementary information such as ambient temperature in the log book under the ID number for that observation.

Only about six or eight channels may be needed for measuring the ozone concentration in the air and rejecting a few interferences. (Seven channels have nonzero coefficients in the processing scheme delivered with the instrument.) In this case better results can be obtained by only looking at these few wavelengths, rather than by spending time looking at a larger number of wavelengths, most of which are essentially unused. On the other hand, for surveying the spectra of the air in a new location many spectral channels may be desired. In other words, although a general purpose list of wavelength channels can be used, and were delivered with the instrument, better results can be achieved on any specific problem by using only those wavelength channels required by the problem.

3.1 PROGRAM FLOW

The Ozone Monitor software for the PDP-8/L consists of an initializing routine (INIT), an auxiliary computation and output routine (AUX), an interrupt service routine (ISR) to provide timely control of the instrument, and subroutines for control of filter wheel positioning and error exits. The flow charts shown in Figures 3-1 through 3-4 exhibit the logical structure of these programs.

Table 3-1 defines the variables which appear on the flow charts. The variables are listed in order of first appearance to assist the reader in following the logical flow of the program. The decision branches are numbered approximately sequentially, and at each of these points the computer will be asked whether a specified flag is zero or whether a certain inequality is satisfied by certain variables. Additional assistance in interpretation can be gained from a study of the tabulated questions which appear in Table 3-2.

3.1.1 INIT Routine

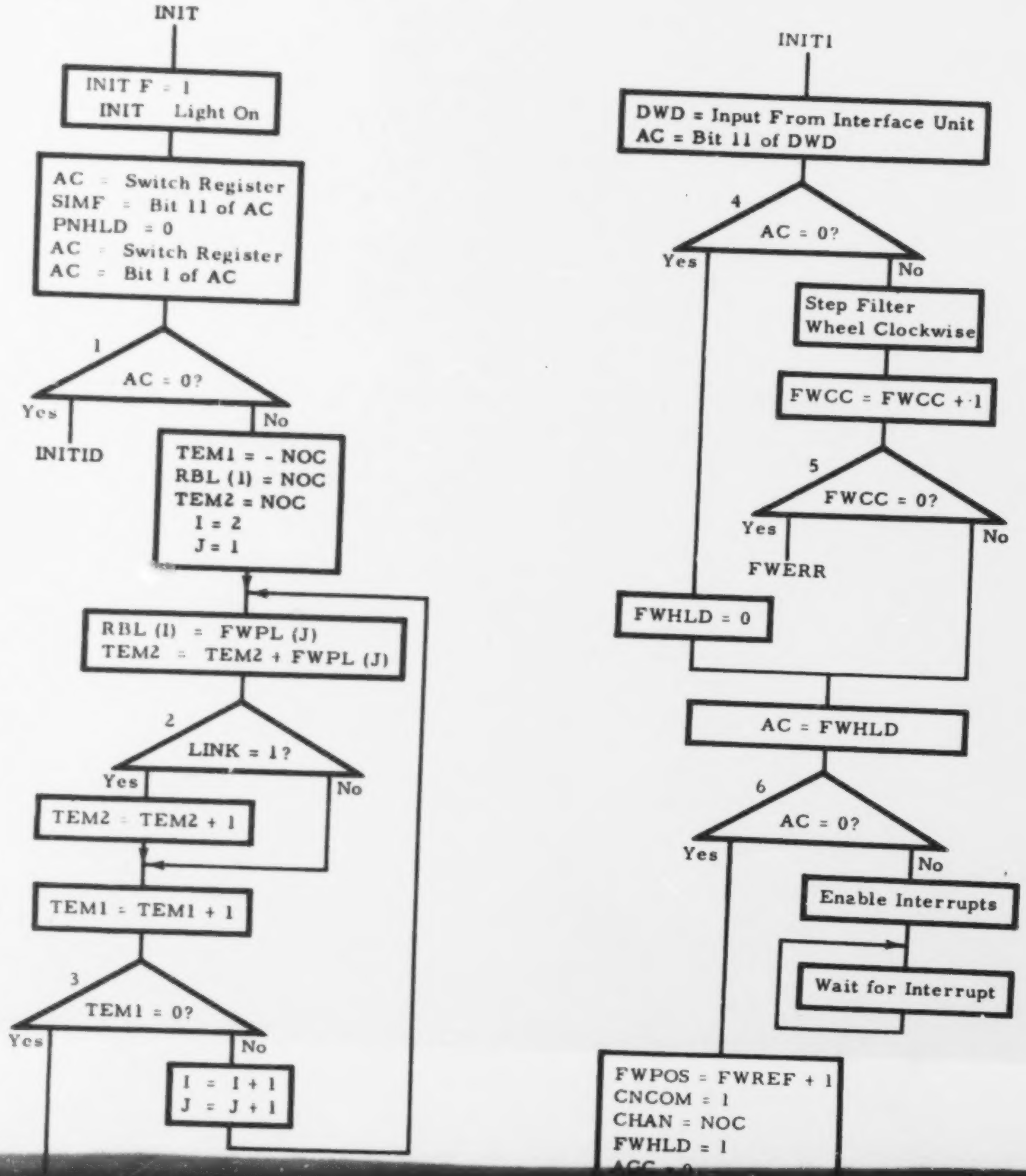
INIT consists of three main branches (Figure 3-1) each of which appears as a separate column on the flow chart. The first branch is executed once to perform initializing operations required before the instrument begins routine activities. The purpose of this branch is to determine the operator instructions as set on the switch register and to set the program control flags which will return control to INIT upon completion of ISR activities. The first branch also punches out the filter wheel position list if this is desired. The non-zero value of INITF, set in the execution of Branch 1, causes ISR to return control to INIT without first enabling interrupts.

After the first interrupt, which will occur after the completion of Branch 1, each successive interrupt will occur at the end of Branch 2 until the filter wheel is mechanically positioned to its reference position. When Branch 2 is completed, control is passed to location INIT 7, the beginning of the third branch, instead of to the Interrupt Service Routine. INIT 7 is executed once to set the values of all remaining variables and to set INITF equal to zero so that future interrupts will not return control to INIT 1, the starting location of the second branch. Branch 3 then enables interrupts and passes control to the auxiliary routine beginning at location AUX.

3.1.2 Auxiliary Routine (AUX)

The purpose of the auxiliary routine (Figure 3-2) is to perform Teletype output operations and numerical computations. These activities are carried out during times when the computer might otherwise be resting from its instrument control obligations. While awaiting interrupts from the output hardware or the chopper wheel, the computer is afforded sufficient free time to process the channel readings for detection processing. Teletype and punch outputs delivered by AUX include the list of channel readings with ID code appended and the pollutant concentration messages.

8378-3


INIT
INIT F = 1
INIT Light On
AC = Switch Register
SIMF = Bit 11 of AC
PNHLD = 0
AC = Switch Register
AC = Bit 1 of AC
1
AC = 0?
Yes
No
INITID
TEM1 = - NOC
RBL (1) = NOC
TEM2 = NOC
I = 2
J = 1
RBL (I) = FWPL (J)
TEM2 = TEM2 + FWPL (J)
2
LINK = 1?
Yes
No
TEM2 = TEM2 + 1
TEM1 = TEM1 + 1
3
TEM1 = 0?
Yes
No
I = I + 1
J = J + 1
INIT1
DWD = Input From Interface Unit
AC = Bit 11 of DWD
4
AC = 0?
Yes
No
Step Filter
Wheel Clockwise
FWCC = FWCC + 1
5
FWCC = 0?
Yes
No
FWERR
FWHLD = 0
AC = FWHLD
6
AC = 0?
Yes
No
Enable Interrupts
Wait for Interrupt
FWPOS = FWREF + 1
CNCOM = 1
CHAN = NOC
FWHLD = 1

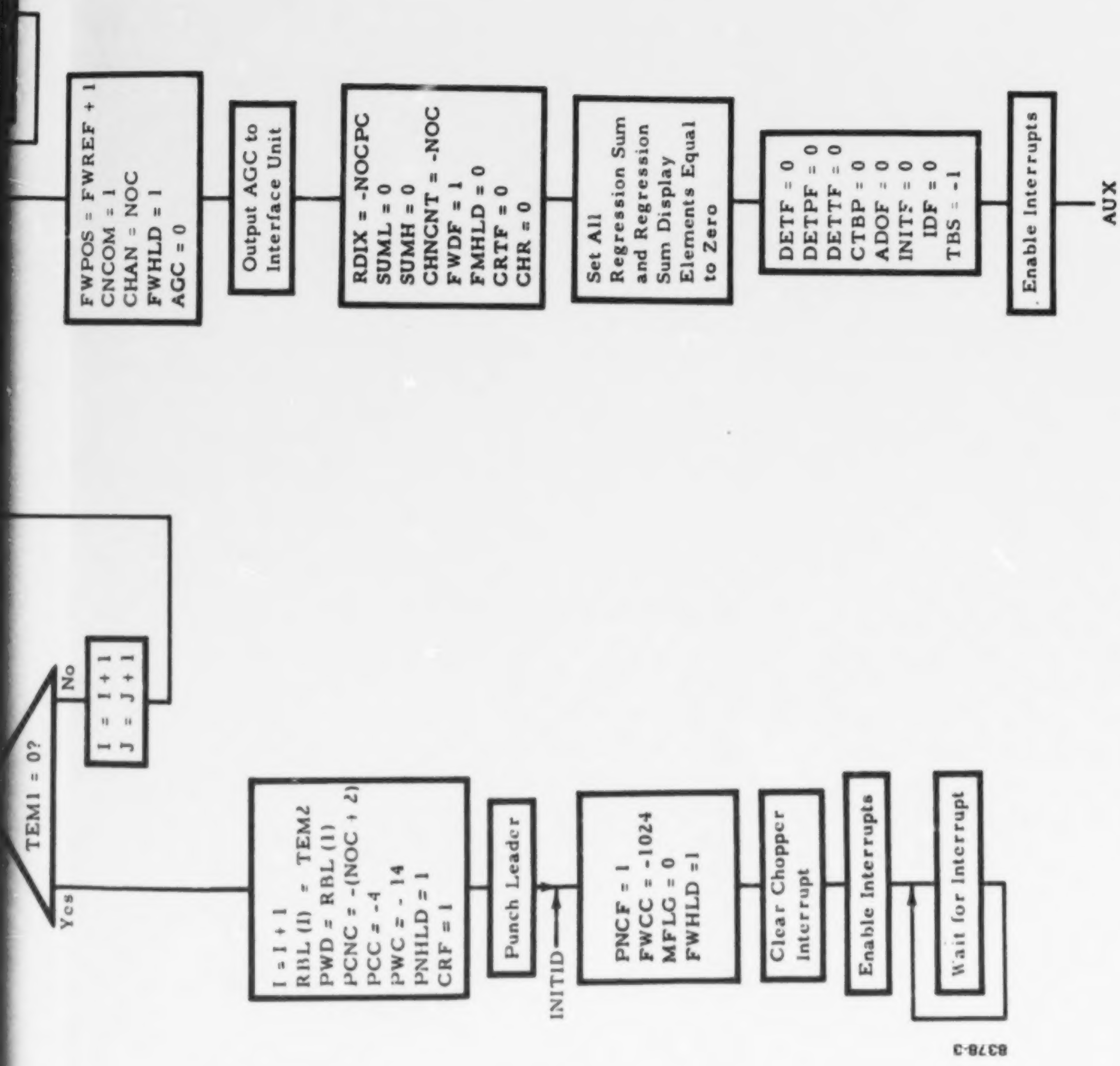
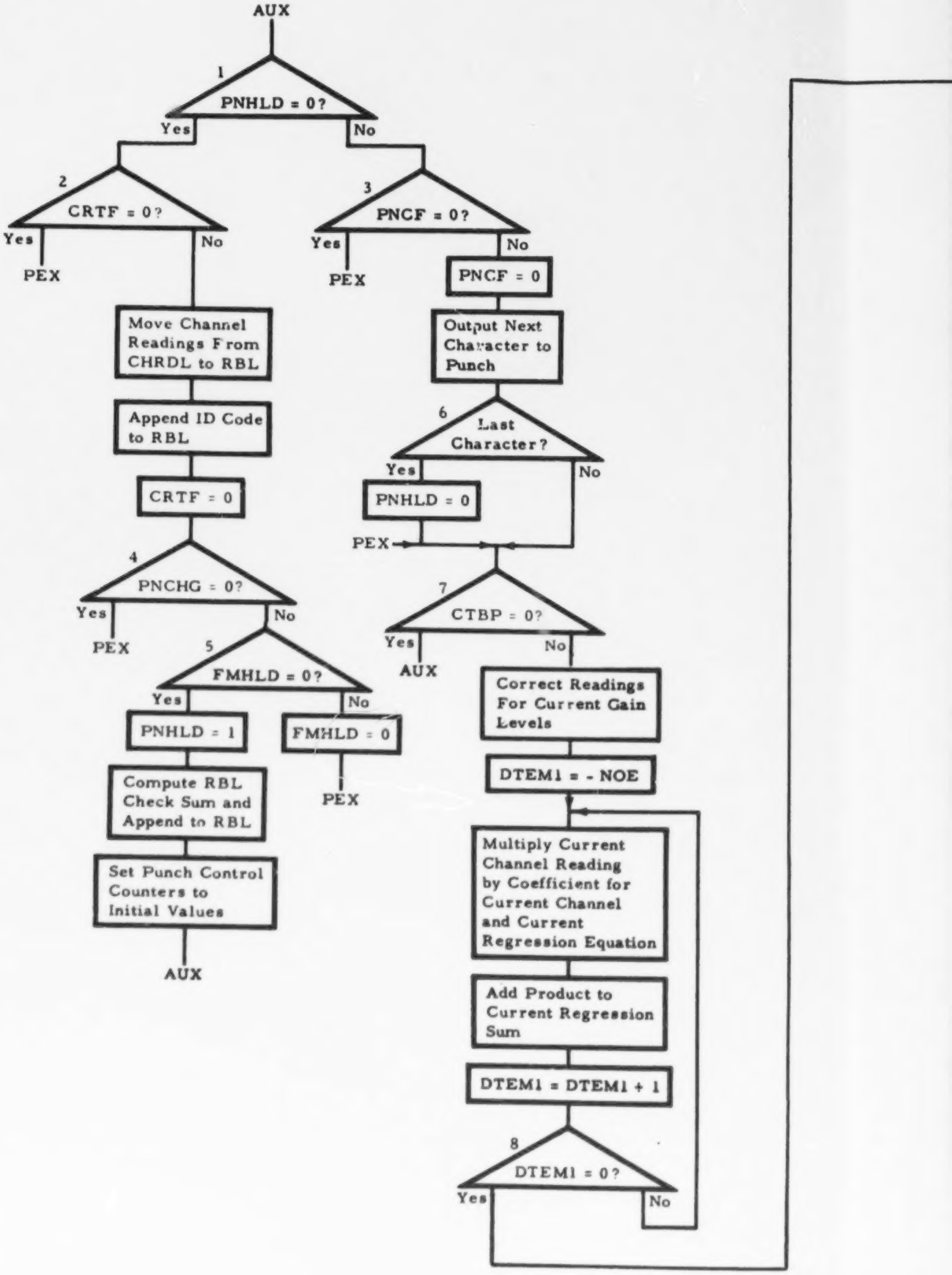


Figure 3-1 Initialize Routine

B


AUX
1
PNHLD = 0?
Yes
No
2
CRTF = 0?
Yes
No
PEX
3
PNCF = 0?
Yes
No
PEX
PNCF = 0
Move Channel Readings From CHRDL to RBL
Output Next Character to Punch
Append ID Code to RBL
6
Last Character?
Yes
No
CRTF = 0
PNHLD = 0
PEX
4
PNCHG = 0?
Yes
No
PEX
7
CTBP = 0?
Yes
No
AUX
5
FMHLD = 0?
Yes
No
PNHLD = 1
FMHLD = 0
PEX
Correct Readings For Current Gain Levels
DTEM1 = - NOE
Compute RBL Check Sum and Append to RBL
Set Punch Control Counters to Initial Values
AUX
Multiply Current Channel Reading by Coefficient for Current Channel and Current Regression Equation
Add Product to Current Regression Sum
DTEM1 = DTEM1 + 1
8
DTEM1 = 0?
Yes
No

8378-7

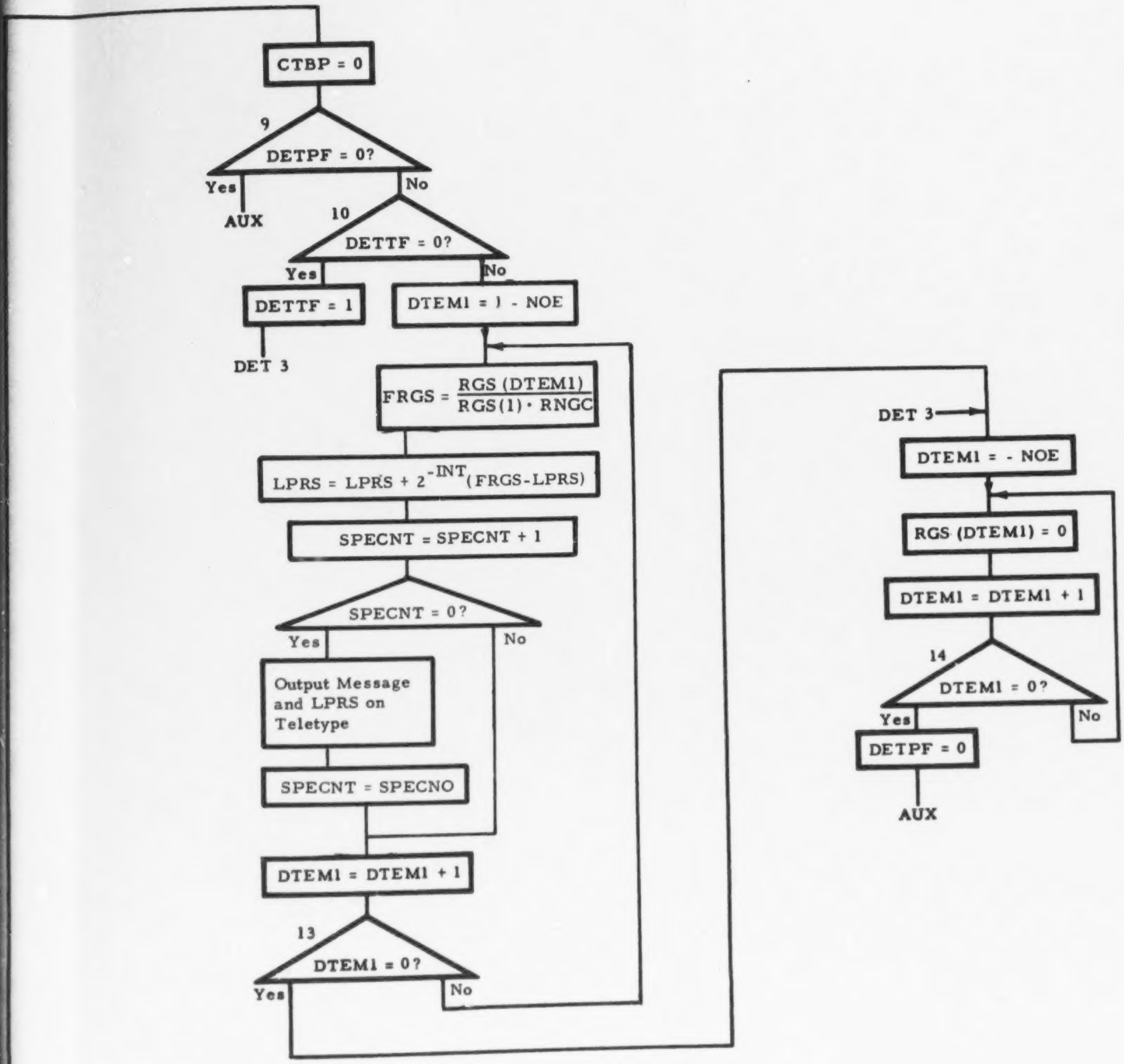


Figure 3-2 Auxiliary Routine

B

BLANK PAGE

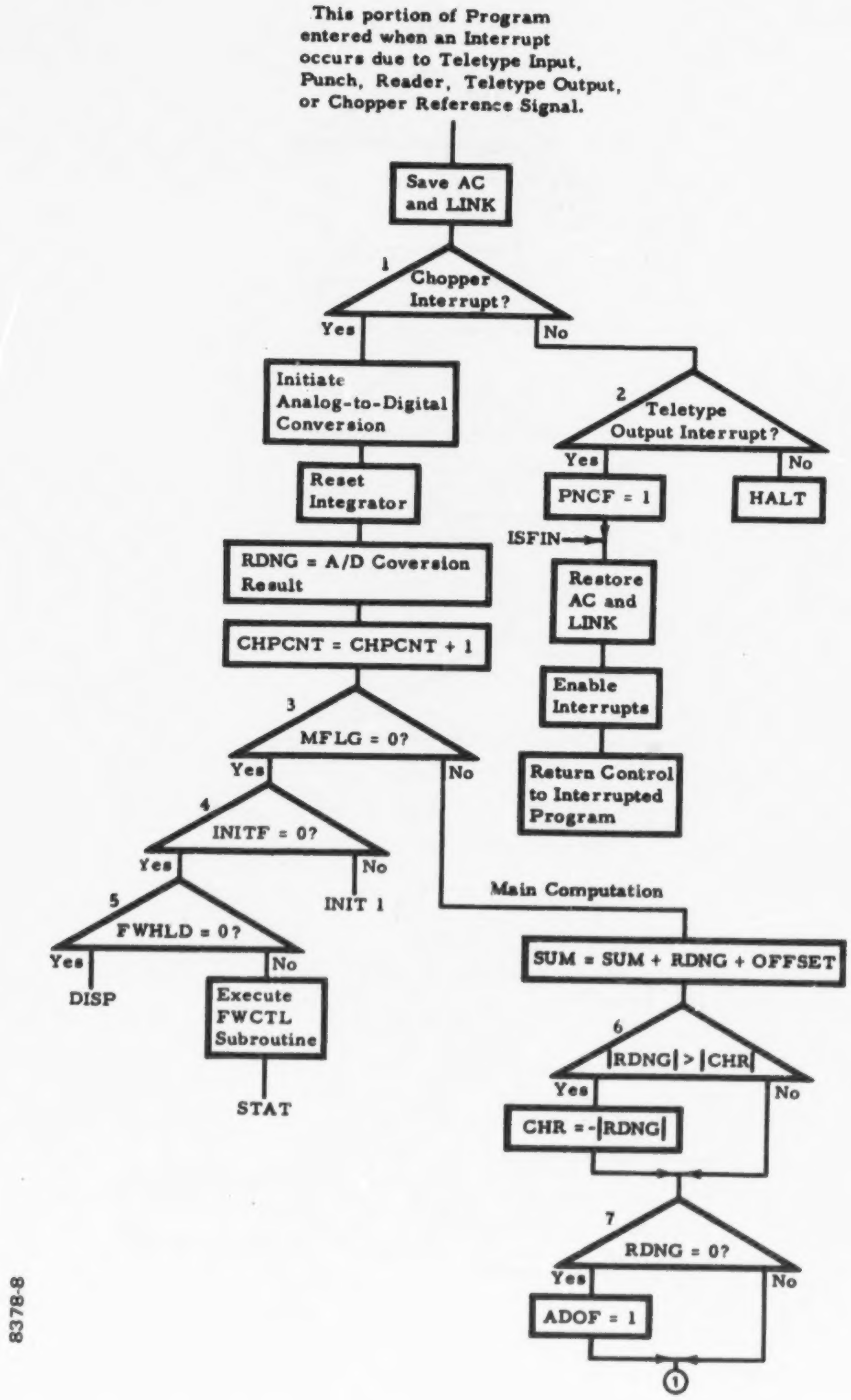


Figure 3-3 Interrupt Service Routine
(Page 1 of 5)

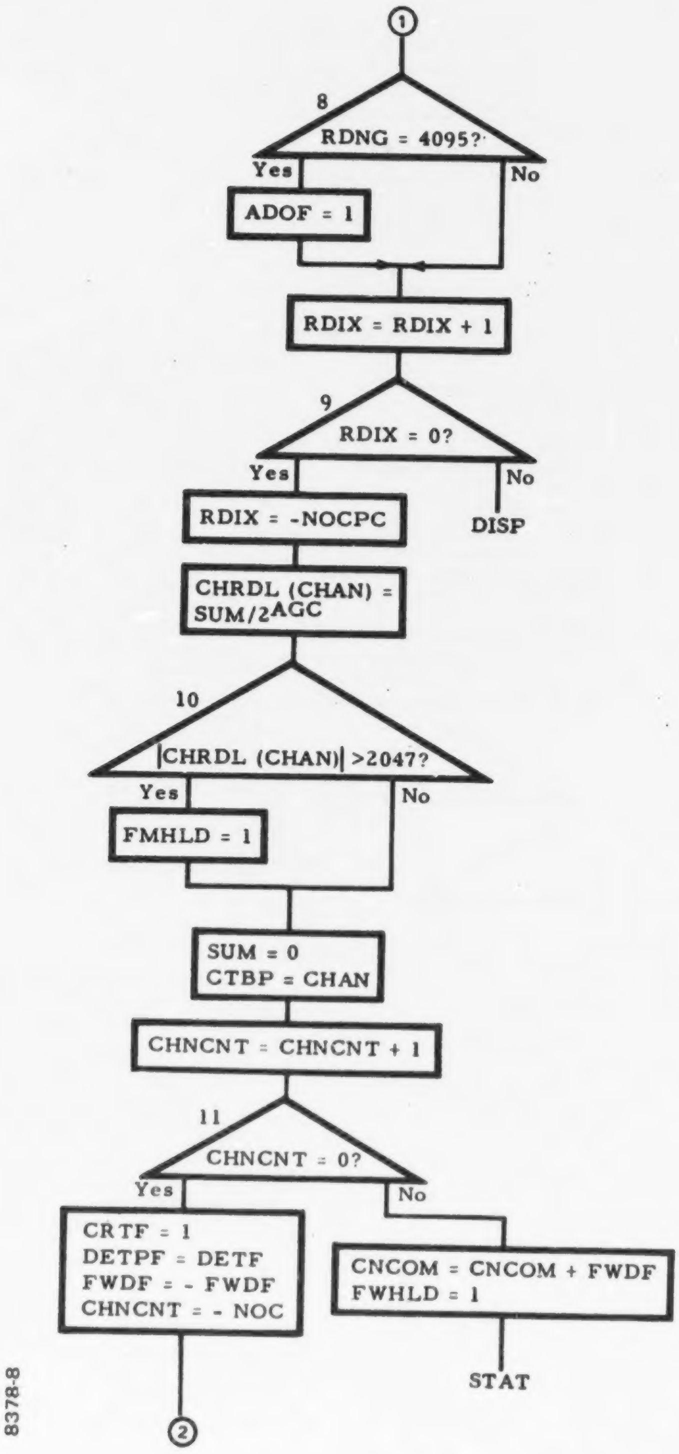


Figure 3-3 Interrupt Service Routine
(Page 2 of 5)

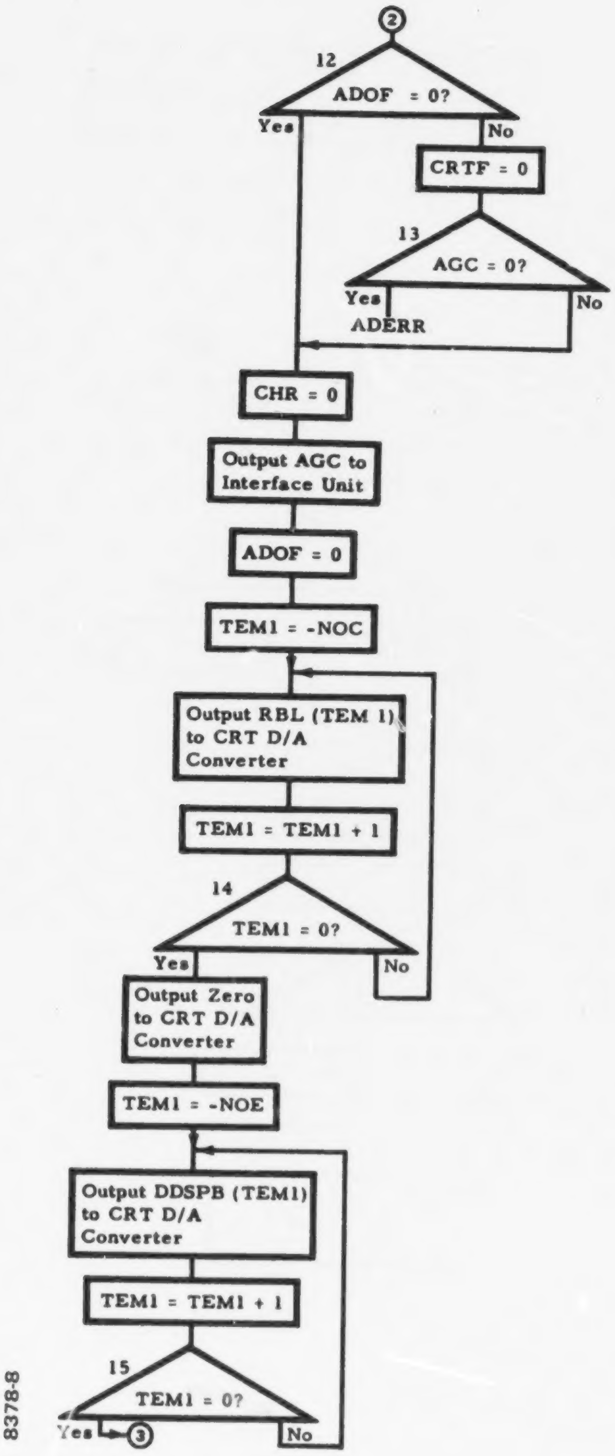


Figure 3-3 Interrupt Service Routine
(Page 3 of 5)

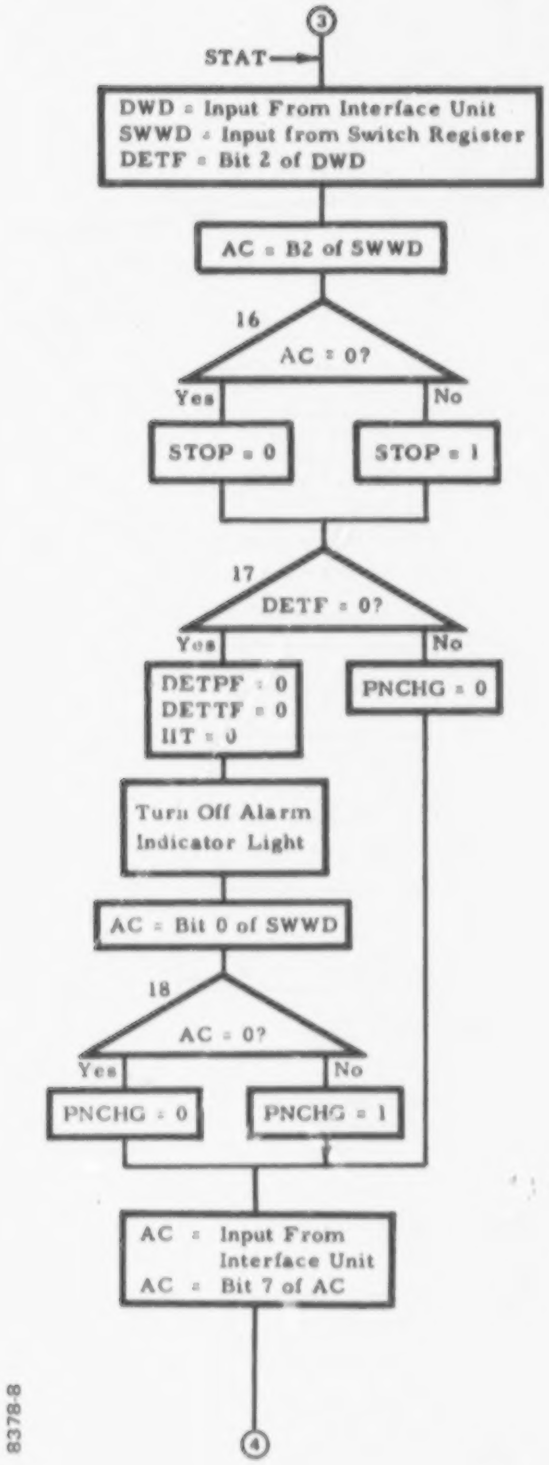
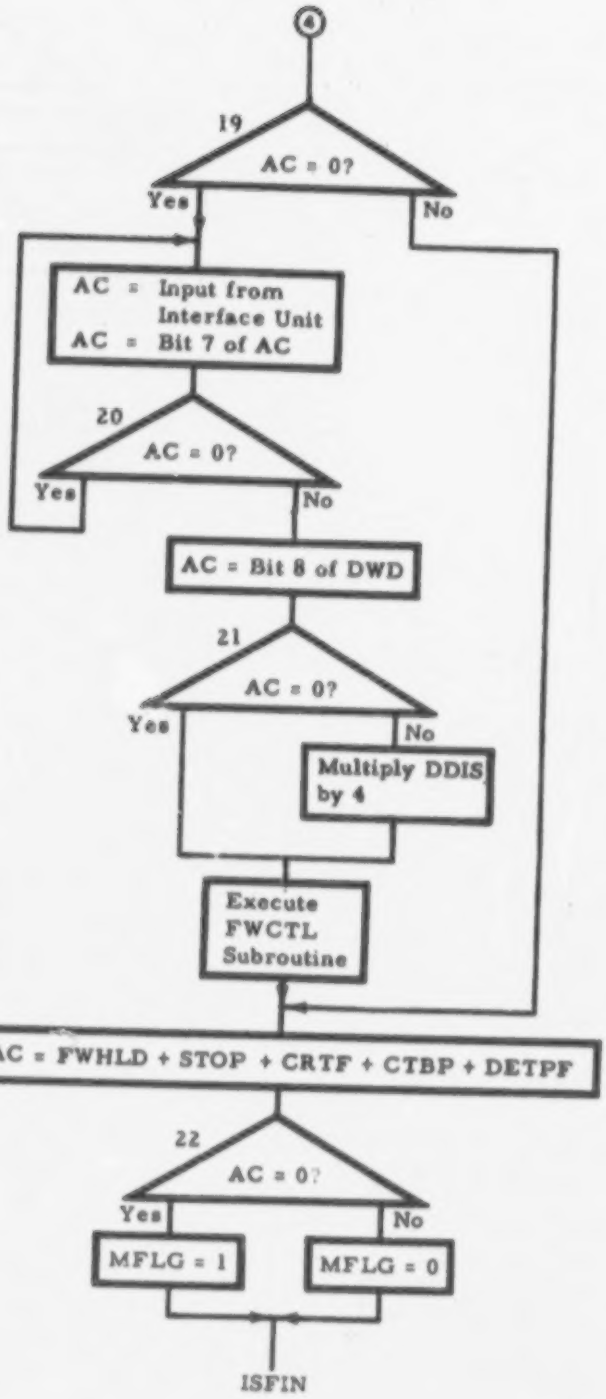


Figure 3-3 Interrupt Service Routine
(Page 4 of 5)



8378-8

Figure 3-3 Interrupt Service Routine
(Page 5 of 5)

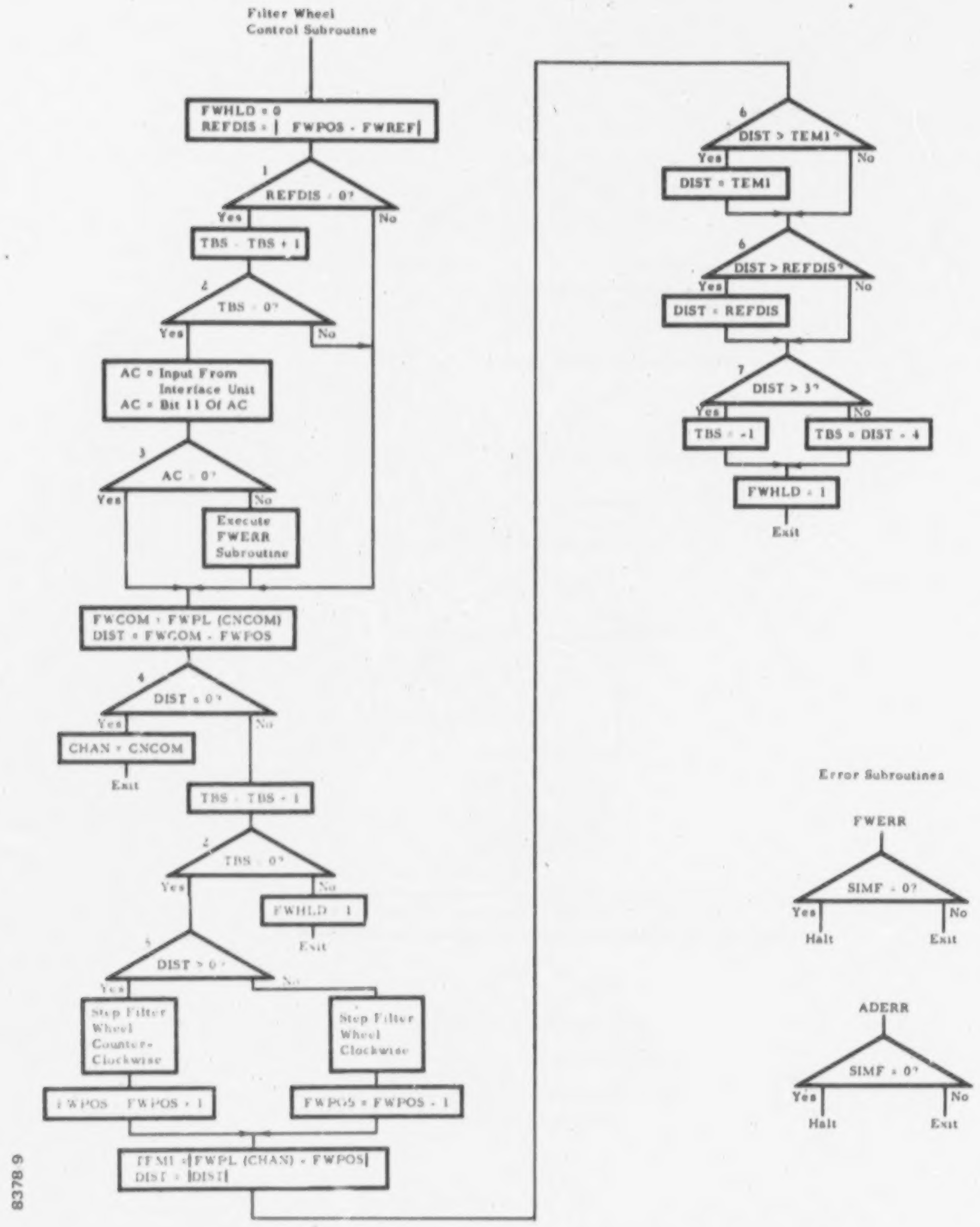


Figure 3-4 Subroutines

TABLE 3-1

GLOSSARY OF COMPUTER PROGRAM SYMBOLS

Variable Name	Acronym	Purpose
INITF	Initialize flag	One for initializing; zero otherwise
AC	Contents of the accumulator	
SIMF	Simulate flag	One for no halts due to instrument errors; zero otherwise
PNHLD	Punch hold flag	One for punching operation in progress; zero otherwise
TEM 1	Temporary storage location	
INIT	Instruction location in INIT routine	
NOC	Number of channels	
RBA Array	Read buffer list	
TEM 2	Temporary storage location	
I, J	Dummy indices	
FWPL Array	Filter wheel position list	List of desired filter wheel positions
LINK	PDP-8 hardware overflow bit	
PCNC	Punch channel counter	Keeps track of punching progress
PCC	Punch character counter	Keeps track of punching progress
PWD	Punch word	Location containing data to be punched next
CRF	Carriage return flag	One for carriage return next punch operation
FWCC	Filter wheel control counter	
MFLG	Main flag	One means enter main computation; zero if hold
STOP	Stop flag	One if operator wants to stop action zero otherwise
IDF	ID flag	One if ID is to be incremented
DPSR	Double precision shift right	Address of routine which multiplies double precision numbers by one half
DPSL	Double precision shift left	Routine multiplies double precision numbers by two
FWHLD	Filter wheel hold	One means filter wheel is not where it belongs; zero otherwise

8378-B

TABLE 3-1 (CONT.)

DWD	Discrete word	Instrument condition input from interface unit
CHPCNT	Chop count	Incremented by one for every chop
FWREF	Filter wheel ref position	
CNCOM	Channel command	Channel to which filter wheel should be moved
CHAN	Channel	Current channel number
AGC	Automatic range control	Index of signal gain provided by system
RDIX	Reading Index	Counts chops
NOCPC	Number of chops per channel	Number of desired chops per channel
SUM L	Sum Low	Least significant portion of integrator sum.
SUM H	Sum High	Most significant portion of integrator sum.
CHNCNT	Channel count	Keeps track of channel number
FWDF	Filter wheel direction flag	Plus or minus one; sense indicates direction of next filter wheel rotation
FMHLD	Format hold	One if format overflow has occurred
CRTF	Channel reading transfer flag	One if the current spectral scan is complete
CHR	Complement of highest reading	Maximum reading obtained during spectral scan
DETF	Detection flag	Assigned the value of Bit 2 of switch register for operator request
DETPF	Detection processing flag	Internal flag set to equal DETF when regression sums are ready for evaluation
CTBP	Channel to be processed next	Set to channel number when a reading is ready for contribution to regression sum; zero otherwise
ADOF	A/D overflow	Set if A/D conversion overflow occurs
TBS	Time between (filter wheel) steps	
AUX	Auxiliary routine	Routine for punching operations and detection processing
PEX	Punch exit location	
CHRDL	Channel reading list	Values entered in main computation of interrupt service routine

8378-B

TABLE 3-1 (CONT.)

PNCHG	Punching	One if operator has called for paper tape data output
PNCF	Punch ready flag	One if punch is in condition to receive next characters
DTEM	Detection processing temporary storage location	Keeps track of the regression equation being evaluated
NOE	Number of equations	Number of regression equations to be evaluated
DETTF	Detection test flag	One if a complete regression sum is available for testing
INTC	Low pass constant	
MDT	Minimum delta temp	No contrast threshold
RGS Array	Regression sums	One value for each regression equation evaluated
FRGS	Fudged regression sum	
LPRS	Low passed regression sum	
DDSPB (Array)	Detection display buffer	Alarm information for oscilloscope display
DISP	Display	Location initiating CRT display routine in ISR
ISR	Interrupt service routine	
STAT	Status	
OFFSET	Offset	Electrical offset correction
SWWD	Switch word	Operator instruction input from switch register
REFDIS	Ref distance	How far the filter wheel is from its reference position
TBS	Time between steps	
DIST	Distance	Number of steps required to move filter wheel to the next desired position
SPECNT	Spectrum count	
SPECND		Number of spectra to be skipped between outputs
RNGC	Range constant	Range between transmitter and receiver in kilometers

8378-B

TABLE 3-2

PROGRAM BRANCH EXPLANATIONS

INIT Routine

1. Is initial printout of filter wheel position to be skipped?
2. Has overflow occurred on the most recent addition?
3. Has reading of filter wheel position list been completed?
4. Has filter wheel reached the reference position?
5. Has a filter wheel position error occurred?
6. Is filter wheel properly positioned?

AUX Routine

1. Is a spectral scan completely punched?
2. Is a spectral scan in progress?
3. Can next character be punched?
4. Is punch output required?
5. Can punch output format accommodate readings?
6. Is spectral scan completely punched?
7. Should detection processing be skipped for the channel available?
8. Has the current channel reading been included in each regression sum being evaluated?
9. Has the last channel been included in each regression sum?
10. Have all channels been included in each regression sum?
11. First value of RGS is the estimate of the signal level for the spectrum; is there sufficient signal for valid detection processing?
12. Does the current value of RGS exceed the alarm level?
13. Have all regression sums been tested?
14. Have all regression sums been reset to zero?

ISR Routine

1. Did the chopper reference signal cause this interrupt?
2. Did the interrupt occur because of a completed teletype output?
3. Do peripheral activities remain to be completed before a reading is accepted?

8378-C

TABLE 3-2 (CONT.)

4. Has initializing been completed?
5. Is the filter wheel properly positioned?
6. Is this the largest reading so far?
7. Is the reading too small?
8. Is the reading too large?
9. Has the proper number of readings been summed?
10. Is the channel reading too large for punch output format?
11. Has a spectral scan been completed?
12. Did all readings during the last spectral scan fall within the range permitted?
13. Is gain at minimum value?
14. Have all channel readings been displayed on the CRT?
15. Has alarm display been completed?
16. Has operator requested STOP action?
17. Has the operator instruction for detection processing been given? (The negative of this question is asked.)
18. Has the operator instruction for data gathering been given? (The negative of this question is asked.)
19. Are peripheral activities completed?
20. Has times four request been given?

Subroutines

FWCTL Subroutines

1. Is the filter wheel at its reference position?
2. Has sufficient time elapsed since last step?
3. Is the filter wheel position reference light signal on?
4. Is the filter wheel in the desired position?
5. Must the filter wheel be moved counter clockwise to reach the next desired position?
6. Locate the smallest of three values.
7. Is the smallest value larger than three?

Filter Wheel and A/D Error Subroutines

1. Should evidence of error of the type indicated be honored?

8378-C

AUX examines various flags to determine if the user desires punched or printed output and if a complete set of spectral readings is ready for outputting. The first of these variables to be examined in the AUX routine is PNHLD. If a non-zero value has been previously assigned to this flag, then an output via the punch is immediately completed. If this condition is not met, the routine inquires of the CRTF, the channel reading transfer flag, whether a completed list of channels is ready to be transferred to the output buffer list. If so, the transfer is effected. Only after the processed channel readings have been transferred is the question asked whether the operator desires an output of the spectrum. This question takes the form of testing the flag PNCHG for a non-zero value. This flag will be non-zero if the user has signified his choice of this option by pushing the PUNCH DATA button. A similar flag is interrogated to ensure that the output can be accommodated by the display format. Only after the data have passed all of these tests is the flag PNHLD set to a non-zero value establishing the condition for punching on the next pass through AUX. Upon punching the last character on the list, the program resets PNHLD to zero. When the user calls for detection processing, this output is automatically suppressed by assigning PNCHG equal to zero in ISR. In this case, CRTF = 0 signals the program to transfer control to location PEX where the detection processing algorithms are evaluated. In a similar manner, the first part of AUX senses the PRINT DATA request if it has been entered at the console. As mentioned previously, this results in the printing of a decimal representation of the channel readings on the Teletype.

The rest of the routine is concerned with detection processing. Following the location called PEX, each channel reading is multiplied by the appropriate coefficients for each of the agents to be detected and the products are added to the running regression sums. The value of DETF, the detection flag, will be non-zero if the user has called for detection processing. When the regression sums are complete, the ISR will assign this value to DETPF. If this flag is non-zero, the detection processing thresholds are compared with the current regression sums and the appropriate messages are printed if they are exceeded. The flag DETTF is initially set to zero in the INIT routine. After its first examination, its value is set to one and control is passed to DET 3 where the regression sums are all set to zero. At the second examination, its value is found to be non-zero and detection processing continues. While the regression sums are always set to zero in INIT, it is possible for the user to turn detection processing off during the computation of sums; this operation reinitializes the values of DETPF and DETTF. Upon a subsequent call for detection processing, the regression sums will be reinitialized without entering INIT before the results are accepted for evaluation.

Each new regression sum becomes part of a weighted average of recent regression sums in order to accomplish the noise reduction obtained from smoothing or filtering. The filter type used is a simple numerical exponential filter with a smoothing constant determined by the quantity INTC.

Measurement outputs on the Teletype occur at intervals determined by the constant SPECNO. The interval will be the time for each spectrum multiplied by SPECNO.

3.1.3 Interrupt Service Routine (ISR)

All other routine activities, with the exception of the subroutines, are performed by ISR (see Figure 3-3). These remaining routine activities are necessarily performed at the pace dictated by the chopper. At the completion of every chop cycle, any other program is interrupted and control is passed to ISR. The address of the next instruction in the interrupted program and the contents of the accumulator and link are stored while ISR activities are completed; control is then returned to the proper location in the interrupted program and the accumulator and link bits are restored. A similar interrupt occurs when the Teletype has completed a character output operation. This interrupt operation is very short, and ISR quickly establishes the nature of the interrupt and control is returned almost immediately to the interrupted program.

The ISR is prepared to handle five kinds of interrupts. An interrupt which passes control to this program occurs whenever: (1) the chopper generates one, (2) the punch completes the output of a character, (3) the Teletype completes the output of a character, (4) the punch completes an input operation, or (5) the Teletype completes an input operation.

A chopper interrupt immediately causes the integrator to be read, A/D converted, and reset. Then, in accordance with the setting of program control flags, the program is required to: (1) add the output of the A/D converter to the running integration sum, or (2) transfer control to the filter wheel control routine, or (3) return to INIT 1 to complete initialization, or (4) jump to the display routines.

The oscilloscope display of the most recently gathered spectrum is regenerated at the chopper interrupt rate of 480 Hz.

The last part of the main interrupt service routine checks on the various operator options selected and reviews the general status of the instrument control processing activities. The flag MFLG is then set to the appropriate state for the next chopper interrupt, and control is returned to the interrupted program. Just prior to this return, the contents of the link and the accumulator are restored to the values they held before the interrupt.

If the interrupt arose from an I/O flag, the program transfers control to the appropriate device selectors for input-output operations. Handling of I/O operations on an interrupt basis is not dictated by the logic of the program; it is a hardware convenience. As such, I/O operations will cause interrupts when the interrupts are enabled. Alternatively, upon receiving an I/O interrupt, the program could be easily directed to return control immediately instead of halting. In this case, however, accidental inputs might alter the operation of the program without warning.

3.1.4 Subroutines

The only major subroutine used in the Ozone Monitor software which is not a part of the standard PDP-8/L programs is FWCTL (see Figure 3-4), the filter wheel control subroutine. This routine is called by ISR when the flag FWHLD is found to be non-zero and the main computation has been bypassed (MFLG = 0). FWCTL is responsible for checking to verify that the filter wheel is stepped to those positions which appear on the filter wheel list. It also looks for the reference pulse from the interface unit which signifies that the wheel is properly referencing its positions. If this latter condition is not met, the error subroutine FWERR is summoned to halt action unless the operation has called for a return to INIT by lifting switch No. 10. The other error subroutine is ADERR, and it is called if the output from the A/D converter is too large for data processing; it too can be suppressed at the discretion of the operator.

3.2 DESCRIPTION OF OUTPUT

When the PRINT DATA button is depressed, the computer will output on the Teletype the channel readings for the most recently gathered spectrum. These numbers are in decimal form. The system will stop gathering spectra while this complete spectrum is being printed.

When the PUNCH DATA button is depressed, the spectrum will be output on the high-speed punch. This punches at a rate of 50 characters per second which is five times faster than the Teletype. The tapes punched by this device are in hexadecimal form. Hexadecimal numbers contain more information in four output digits than do decimal numbers. The spectra on these tapes can be subjected to statistical analysis on a large computer to determine the best set of channels and operating coefficients for use in detecting pollutants in the presence of spectral interferences. Further detail on these statistical programs can be found in the referenced document* and in Section 4 of this report.

---

* Bendix Aerospace Systems Division, "Computer Analysis of Spectral Data," by Robert H. Dye and Arnold Prostak, Final Report BSR 2830, Volume 2, Contract No. DAAA15-68-C-0521, December 1969.

SECTION 4

OFF-LINE DATA PROCESSING

An IBM-360/50 computer was programmed in FORTRAN IV to handle the large quantities of spectral data obtained on punched paper tape.

A program called HEXED (for hexadecimal editor) converts the data on paper tape, which are in the hexadecimal number system, to the decimal number system. The data are in hexadecimal because they transmit more information per punch character. The HEXED program also computes a checksum for each spectrum and compares it with a checksum punched on the tape to reject spectra containing errors due to tape punch or tape reader malfunction. Figure 4-1 shows an example of HEXED printed output.

The OMAS (for Ozone Monitor Absorption Simulator) Program computes the transmittance that would be in each spectral channel if there had been an amount of ozone in the beam giving a specified peak fractional absorptance. This computed transmittance takes into account the spectral bandwidth of the Ozone Monitor and is needed to simulate ozone-containing spectra. Figure 4-2 shows an example of OMAS printed output.

The stepwise regression program computes a sequence of multiple linear regression equations in a stepwise manner. At each step, one variable is added to the regression equation. The variable added is the one which makes the greatest reduction in the error sum of squares. Equivalently, it is the variable which has the highest partial correlation with the dependent variable partialed on the variables which have already been added; and equivalently it is the variable which, if it were added, would have the highest F value. In addition, variables can be forced into the regression equation and automatically removed when their F values become too low. In addition, after all the significant variables are in the regression equation, this program deletes one variable at each step. The variable deleted is the one with the smallest F value. Regression equations with or without the regression intercept may be selected.

8378-15

```
ERROR LEGEND:
        LF=0, LINE FEED OKAY
        LF=1, LINE FEED IN ERROR
        CR=0, CARRIAGE RETURN OKAY
        CR=1, CARRIAGE RETURN IN ERROR
        0 OR 1 PRINTED UNDER VARIABLE, WHERE, 0 INDICATES NO ERROR, 1 INDICATES ERROR.
FILTER POSITION LIST
          9         19         29         39         48         57         66         75         64         93
        101        110        118        124        130        135        141        146        151        157
        162        168        173        179        184        189        195        200        205        213
        222        230        238        246        254        262        271        279        287        296
        304        313        322        330        339        349        358        367        377        367
CASE NO.      1 ID NO.      50
    -0.6875     5.2500     1.0625    21.5625    42.3750    66.1250    96.2500   147.0625   148.5625   144.7500
   155.2500   145.4375   132.8125   125.8125   109.6750   131.0625   125.9375   125.3750   122.3750   127.6875
   140.8125   132.8750   125.5000   134.4375   129.4375   126.3125   121.6875   125.0625   109.0625    96.5625
    64.0625   101.0000   103.1875    88.4375    84.4375    75.0000    56.3125    59.6875    56.3125    50.5625
    42.1875    29.0625    22.8125    24.3750    21.9375    24.0000    19.6875    12.0625     4.1875     5.8125
CASE NO.      2 ID NO.      50
     4.5625     3.5000     8.0000    14.6875    29.1875    61.8750   105.1250   151.3125   143.6250   146.8125
   142.0625   133.6875   124.3125   113.1250   114.6875   123.1250   132.5625   121.8125   123.2500   132.6875
   124.6250   125.5625   117.3750   130.8750   132.2500   135.7500   123.6875   131.4375   121.1250    98.0625
    80.0000   100.0000    93.7500    86.6250    76.6875    74.3125    61.9375    58.9375    60.5000    48.1250
    32.1875    31.7500    23.5000    26.1875    23.3125    23.7500    19.2500     8.7500     2.3750     5.5000
CASE NO.      3 ID NO.      50
    -0.6250     4.4375    -2.0625    17.5625    42.8125    64.0625   110.4375   135.0625   150.6875   131.6250
   151.1250   134.9375   115.5625   113.0625   112.3125   125.3750   122.6875   117.3125   129.6875   138.7500
   136.0000   137.6875   140.4375   134.5000   134.3750   132.0000   122.8125   129.5625   125.0000   105.3125
    70.6250    97.3750    97.4375    87.8750    78.3750    69.0625    64.5625    58.7500    52.1875    53.6875
    39.6250    33.8125    21.6250    27.0000    27.6875    22.1875    17.9375    11.8125     5.6250     7.5625
CASE NO.      4 ID NO.      50
     2.1250     4.1250     1.0625    16.6875    29.7500    60.0625   110.3125   129.5625   152.0625   133.3125
   138.3750   135.1250   115.9375   124.2500   115.7500   115.6875   133.8125   130.2500   124.1875   149.2500
   138.0625   138.1875   129.5000   128.4375   129.0625   121.8750   116.1875   126.0625   117.3125   102.5000
    86.7500    90.5625    90.7500    80.9375    79.3750    75.6875    58.8125    61.8125    52.9375    51.1875
    41.5000    26.0625    24.2500    23.0000    22.2500    17.8125    13.9375    12.9375     8.8125     9.8125
CASE NO.      5 ID NO.      50
    -0.9375     4.4375     8.0625    16.2500    33.8125    54.6250   110.0000   136.3750   147.3125   135.5000
   150.4375   139.8125   119.6250   111.0625   112.1250   127.5000   123.5000   124.3125   123.6875   121.7500
   123.0000   119.3750   116.0000   130.1250   130.3750   123.8125   109.8125   112.8750   120.6250    95.4375
    84.9375    89.5000    85.9375    83.1250    75.7500    77.5000    56.1250    53.6250    55.9375    48.8750
    42.0625    31.9375    23.3750    27.5625    20.9375    23.1875    19.5000    13.0000     6.6250     4.0000
CASE NO.      6 ID NO.      50
     7.1250     3.3125     6.1875    14.5625    33.6250    62.1250    98.9375   152.0000   146.9375   140.5625
   138.1250   119.3750   126.1250   115.2500   108.1250   120.9375   129.4375   114.5625   112.3750   136.3125
   128.4375   124.3125   121.5625   138.3125   142.1875   129.5625   125.5625   119.0000   121.3750   102.1250
    73.3125   101.3125    89.3750    84.0000    74.6250    70.0000    63.0625    62.9375    55.5000    49.8750
    33.6875    33.0000    18.6875    36.1875    24.5625    25.5625    24.3750     8.0625     6.1875     6.3125
CASE NO.      7 ID NO.      50
    -4.1875     3.6250     4.4375    18.0625    40.9375    71.2500   115.6875   141.2500   159.2500   125.0625
   148.6250   136.7500   110.6250   113.7500   102.8750   120.3750   134.8750   132.1250   125.2500   124.8125
   130.6875   124.6875   117.4375   133.1250   140.1250   137.0625   124.0625   120.3125   104.1250    90.8750
    73.9375    92.7500    95.8750    85.1250    73.0000    74.7500    60.3125    65.5625    60.5000    50.1875
    41.9375    30.0000    22.9375    26.0000    23.9375    26.6875    16.8750    16.0000     1.7500     6.0000

CARD READ:     000B   0001   0069   00C7   024D   03DC   0618   08C3   096A   08BE   087E   07AC   07DE   072C   06F2   07C9

CARD READ:     070E   C745   0821   C799   0813   0786   0826   07BF   088F   088F   077E   07A4   081E   0654   05C2   05E1

CARD READ:     059C   052B   0510   0439   0464   03D1   0354   030F   0202   01DC   0157   0156   01C6   0170   0175   008B

CARD READ:     0062   C02D   0032   FD88   :

ABOVE SET WAS FOUND UNACCEPTABLE. SUM (      64913) DOES NOT AGREE WITH CHECKSUM (      64904).
```

Figure 4-1 Output From HEXED Program

D

```
8378-16

PEAK ABSORPTION =15.0 PERCENT
CLEAR-TO-AGENT CASE RATIO =    1  BW= 0.15 MICRONS


OZONE


CL=  340.13989 MICROGRAM-KILOMETERS PER CUBIC METER

 I   WAVELENGTH   ALPHA   PCNT ABSORPTION   TRANSMISSION   CHAN   FWPOS   WEIGHTED TRANSMISSION


  1     7.50      0.0         0.0             1.00000
  2     7.55      0.0         0.0             1.00000
  3     7.60      0.0         0.0             1.00000        4      39          1.00000
  4     7.65      0.0         0.0             1.00000
  5     7.70      0.0         0.0             1.00000
  6     7.75      0.0         0.0             1.00000        5      48          1.00000
  7     7.80      0.0         0.0             1.00000
  8     7.85      0.0         0.0             1.00000
  9     7.90      0.0         0.0             1.00000        6      57          1.00000
 10     7.95      C.0         0.0             1.00000
 1i     8.00      0.0         0.0             1.00000
 12     8.05      0.0         0.0             1.00000        7      66          1.00000
 13     8.10      0.0         0.0             1.00000
 14     8.15      0.0         0.0             1.00000
 15     8.20      0.0         0.0             1.00000        8      75          1.00000
 16     8.25      0.0         0.0             1.00000
 17     8.30      0.000       0.000           1.00000
 18     8.35      0.000       0.000           1.00000        9      84          1.00000
 19     8.40      0.000       0.000           1.00000
 20     8.45      0.000       0.001           0.99999
 21     8.50      0.009       0.030           0.99970       10      93          0.99987
 22     8.55      0.012       0.042           0.99958
 23     8.60      0.016       0.053           0.99947
 24     8.65      0.017       0.058           0.99942       11     101          0.99950
 25     8.70      0.024       0.082           0.99918
 26     8.75      0.029       0.097           0.99903
 27     8.80      0.048       0.164           0.99836       12     110          0.99883
 28     8.85      0.059       0.199           0.99801
 29     8.90      0.062       0.210           0.99790
 30     8.95      0.044       0.150           0.99850       13     118          0.99824
 31     9.00      0.030       0.102           0.99898
 32     9.05      0.029       0.100           0.99900       14     124          0.99874
 33     9.10      0.033       0.113           0.99887
 34     9.15      0.041       0.140           0.99860       15     130          0.99877
 35     9.20      0.044       0.149           0.99851
 36     9.25      0.046       0.157           0.99843       16     135          0.99818
 37     9.30      0.056       0.189           0.99811
 38     9.35      0.302       1.023           0.98977       17     141          0.98445
 39     9.40      2.102       6.900           0.93100
 40     9.45      4.301      13.610           0.86390       18     146          0.92920
 41     9.50      4.778      15.000           0.85000
 42     9.55      2.322       7.594           0.92406       19     151          0.88972
 43     9.60      1.779       5.872           0.94128
 44     9.65      2.653       8.629           0.91371       20     157          0.91764
 45     9.70      2.853       9.248           0.90752
 46     9.75      2.680       8.713           0.91287       21     162          0.91550
 47     9.80      2.448       7.989           0.92011
 48     9.85      1.920       6.322           0.93678       22     168          0.92651
 49     9.90      1.314       4.371           0.95629
 50     9.95      0.918       3.073           0.96927       23     173          0.95261
 51    10.00      0.572       1.928           0.98072
 52    10.05      0.373       1.260           0.98740       24     179          0.97943
 53    10.10      0.190       0.645           0.99355
 54    10.15      0.115       0.392           0.99608       25     184          0.99160
 55    10.20      0.061       0.208           0.99792
                  0.033       0.112           0.99888       26     189          0.99706
 52   10.05   0.373    1.260    0.98740
 53   10.10   0.190    0.645    0.99355      25     184     0.99160
 54   10.15   0.115    0.392    0.99608
 55   10.20   0.061    0.208    0.99792      26     189     0.99706
 56   10.25   0.033    0.112    0.99888
 57   10.30   0.012    0.042    0.99958      27     195     0.99934
 58   10.35   0.005    0.017    0.99983
 59   10.40   0.003    0.009    0.99991      28     200     0.99986
 60   10.45   0.001    0.003    0.99997
 61   10.50   0.000    0.001    0.99999      29     205     0.99997
 62   10.55   0.000    0.000    1.00000
 63   10.60   0.000    0.000    1.00000
 64   10.65   0.000    0.000    1.00000      30     213     1.00000
 65   10.70   0.0      0.0      1.00000
 66   10.75   0.000    0.000    1.00000
 67   10.80   0.000    0.000    1.00000      31     222     1.00000
 68   10.85   0.000    0.000    1.00000
 69   10.90   0.000    0.000    1.00000
 70   10.95   0.000    0.000    1.00000      32     230     1.00000
 71   11.00   0.0      0.0      1.00000
 72   11.05   0.0      0.0      1.00000
 73   11.10   0.000    0.000    1.00000      33     238     1.00000
 74   11.15   0.0      0.0      1.00000
 75   11.20   0.0      0.0      1.00000
 76   11.25   0.0      0.0      1.00000      34     246     1.00000
 77   11.30   0.0      0.0      1.00000
 78   11.35   0.0      0.0      1.00000
 79   11.40   0.0      0.0      1.00000      35     254     1.00000
 80   11.45   0.0      0.0      1.00000
 81   11.50   0.0      0.0      1.00000
 82   11.55   0.0      0.0      1.00000      36     262     1.00000
 83   11.60   0.0      0.0      1.00000
 84   11.65   0.0      0.0      1.00000
 85   11.70   0.0      0.0      1.00000      37     271     1.00000
 86   11.75   0.0      0.0      1.00000
 87   11.80   0.0      0.0      1.00000
 88   11.85   0.0      0.0      1.00000      38     279     1.00000
 89   11.90   0.0      0.0      1.00000
 90   11.95   0.0      0.0      1.00000
 91   12.00   0.0      0.0      1.00000      39     287     1.00000
 92   12.05   0.0      0.0      1.00000
 93   12.10   0.0      0.0      1.00000
 94   12.15   0.0      0.0      1.00000      40     296     1.00000
 95   12.20   0.0      0.0      1.00000
 96   12.25   0.0      0.0      1.00000
 97   12.30   0.000    0.000    1.00000      41     304     1.00000
 98   12.35   0.000    0.000    1.00000
 99   12.40   0.001    0.003    0.99997
100   12.45   0.002    0.005    0.99995      42     313     0.99992
101   12.50   0.004    0.013    0.99987
102   12.55   0.006    0.022    0.99978
103   12.60   0.007    0.024    0.99976      43     322     0.99973
104   12.65   0.011    0.036    0.99964
105   12.70   0.009    0.030    0.99970
106   12.75   0.013    0.043    0.99957      44     330     0.99958
107   12.80   0.013    0.046    0.99954
108   12.85   0.022    0.074    0.99926
109   12.90   0.019    0.063    0.99937      45     339     0.99929
110   12.95   0.027    0.092    0.99908

111   13.00   0.022    0.074    0.99926
112   13.05   0.027    0.092    0.99908      46     349     0.99900
113   13.10   0.038    0.130    0.99870
114   13.15   0.027    0.093    0.99907
115   13.20   0.053    0.181    0.99819      47     358     0.99865
116   13.25   0.030    0.102    0.99898
117   13.30   0.051    0.175    0.99825
118   13.35   0.046    0.156    0.99844      48     367     0.99845
119   13.40   0.032    0.109    0.99891
120   13.45   0.085    0.290    0.99710
121   13.50   0.037    0.126    0.99874      49     377     0.99813
122   13.55   0.046    0.155    0.99845
123   13.60   0.092    0.313    0.99687
124   13.65   0.047    0.161    0.99839      50     387     0.99749
125   13.70   0.101    0.342    0.99658
126   13.75   0.079    0.268    0.99732
127   13.80   0.102    0.347    0.99653
128   13.85   0.126    0.427    0.99573
129   13.90   0.103    0.350    0.99650
130   13.95   0.140    0.476    0.99524
131   14.00   0.066    0.224    0.99776
```

Figure 4-2 Output From OMAS Program

B

The output from this program at each step includes:

1. Multiple R
2. Standard error estimate
3. Analysis-of-variance table
4. For variables in the equation
    a. Regression coefficient
    b. Standard error
    c. F to remove
5. For variables not in the equation
    a. Tolerance
    b. Partial correlation coefficient
    c. F to enter.

From the regression results, one can select a step which gives a suitably low standard error estimate and use the selected spectral channels and coefficients from that step.

Figure 4-3 shows an example of the printed output of the regression program.

The coefficient converter program converts the selected coefficients into double-precision octal form for insertion via punched paper tape into the PDP-8/L computer. Figure 4-4 shows the printed output of the coefficient converter program.

Another program was used to compute the mean and standard deviations of each spectral channel in a group of spectra having the same identification number. Plotting programs were used to plot individual spectra and averaged spectra on a Calcomp plotter. Some of these machine-plotted spectra are shown elsewhere in this report.

```
8378-17
 STEPWISE REGRESSION - VERSION OF SEPTEMBER 68

  PROBLEM CODE          OZONE
  NUMBER OF CASES                    470
  NUMBER OF ORIGINAL VARIABLES        51
  NUMBER OF VARIABLES ADDED            0
  TOTAL NUMBER OF VARIABLES           51
  NUMBER OF SUB-PROBLEMS               1

 INPUT DATA

     1    -0.00826    0.06307    0.01276    0.25905    0.50909    0.79443    0.0      50
     1     1.15635    1.76681    1.78483    1.73903    1.86517    1.74729    0.0      50
     1     1.59561    1.51151    1.32004    1.57458    1.51301    1.50625    0.0      50
     1     1.47021    1.53404    1.69172    1.59636    1.50776    1.61513    0.0      50
     1     1.54305    1.51752    1.46195    1.50250    1.31028    1.16010    0.0      50
     1     0.76965    1.21341    1.23969    1.06249    1.01443    0.90105    0.0      50
     1     0.70057    0.71709    0.67654    0.60746    0.50684    0.34916    0.0      50
     1     0.27407    0.29284    0.26356    0.28834    0.23653    0.14492    0.0      50
     1     0.05031    0.06983    0.0        0.0        0.0        0.0        0.0      50
     2    -0.00840    0.06412    0.01298    0.26335    0.51754    0.80761    0.0      50
     2     1.17554    1.79614    1.81445    1.76756    1.89518    1.77421    0.0      50
     2     1.61924    1.53467    1.34030    1.59781    1.51420    1.42285    0.0      50
     2     1.32979    1.43106    1.57448    1.50360    1.46014    1.60816    0.0      50
     2     1.55549    1.53818    1.48524    1.52722    1.33199    1.17936    0.0      50
     2     0.78242    1.23355    1.26027    1.08012    1.03127    0.91601    0.0      50
     2     0.71220    0.72899    0.68777    0.61754    0.51525    0.35492    0.0      50
     2     0.27854    0.29758    0.26774    0.29283    0.24013    0.14710    0.0      50
     2     0.05105    0.07081   34.01398    0.0        0.0        0.0        0.0      50
     3     0.05544    0.04253    0.09721    0.17848    0.35467    0.75188    0.0      50
     3     1.27744    1.83869    1.74527    1.78401    1.72628    1.62452    0.0      50
     3     1.51059    1.44756    1.39363    1.49616    1.61084    1.48022    0.0      50
     3     1.49768    1.61236    1.51439    1.52578    1.42629    1.59034    0.0      50
     3     1.60705    1.64958    1.50300    1.59717    1.47186    1.19162    0.0      50
     3     0.97213    1.21516    1.13921    1.05263    0.93188    0.90302    0.0      50
     3     0.75264    0.71618    0.73517    0.58480    0.39113    0.38581    0.0      50
     3     0.28556    0.31822    0.28936    0.28960    0.23392    0.10633    0.0      50
     3     0.02886    0.06683    0.0        0.0        0.0        0.0        0.0      50
     4     0.05634    0.04322    0.09880    0.18138    0.36045    0.76413    0.0      50
     4     1.29824    1.86864    1.77370    1.81283    1.75352    1.64904    0.0      50
     4     1.53249    1.46929    1.41459    1.51777    1.61162    1.39783    0.0      50
     4     1.35422    1.50367    1.40901    1.43668    1.38083    1.58299    0.0      50
     4     1.61951    1.67152    1.52647    1.62296    1.49579    1.21102    0.0      50
     4     0.98796    1.23495    1.15777    1.06978    0.94705    0.91772    0.0      50
     4     0.76490    0.72785    0.74715    0.59432    0.39750    0.39207    0.0      50
     4     0.29014    0.32327    0.29387    0.29301    0.23741    0.10789    0.0      50
     4     0.02928    0.06775   34.01398    0.0        0.0        0.0        0.0      50
     5    -0.00751    0.05331   -0.02478    0.21100    0.51435    0.76965    0.0      50
     5     1.32680    1.62264    1.81036    1.58134    1.81561    1.62114    0.0      50
     5     1.38837    1.41840    1.35533    1.50625    1.47397    1.40939    0.0      50
     5     1.55806    1.66694    1.63390    1.65418    1.68722    1.61588    0.0      50
     5     1.61438    1.57383    1.47547    1.55656    1.50175    1.26522    0.0      50
     5     0.84849    1.16986    1.17061    1.05573    0.94160    0.82972    0.0      50
     5     0.77565    0.70582    0.62698    0.64500    0.47605    0.40622    0.0      50
     5     0.25980    0.32438    0.33264    0.26555    0.21550    0.14192    0.0      50
     5     0.06758    0.09086    0.0        0.0        0.0        0.0        0.0      50
     6    -0.00764    0.05422   -0.02520    0.21459    0.52311    0.78276    0.0      50
     6     1.34940    1.65029    1.84120    1.60807    1.84562    1.64683    0.0      50
```

Figure 4-3 Output From Regression Program (Page 1 of 2)

```
8378-17
 STEP NUMBER                        7
 VARIABLE ENTRD                    22
 MULTIPLE R                         0.9229
 STD. ERROR OF EST.                 9.3392
 RESIDUAL SAMPLE RMS DEV.           9.2694

 ANALYSIS OF VARIANCE
                      DF    SUM OF SQUARES      MEAN SQUARE        F-RATIO
       REGRESSION      7         232079.813        33154.258        380.118
       RESIDUAL      463          40383.301           87.221
                                                     .
             VARIABLES IN EQUATION                   .                  VARIABLES NOT IN EQUATION
                                                     .
   VARIABLE      COEFFICIENT  STD. ERROR  F TO REMOVE  .     VARIABLE    PARTIAL CORR.     TOLERANCE     F TO ENTER
                                                     .
                                                     .
     (CONSTANT       0.0      )                      .
      12          36.78831     4.61565     63.5265  .         1          -0.06186      0.90394706        1.7748
      16          31.85229     5.89114     29.2337  .         2          -0.03771      0.49263632        0.6578
      19         -87.62930     5.67714    238.2538  .         3          -0.24840      0.73553079       30.3822
      21         -34.11340     6.78207     25.3003  .         4           0.07381      0.18425030        2.5308
      22         -38.44629     6.27148     37.5811  .         5          -0.06945      0.10582834        2.2392
      26          48.86093     5.64439     74.9358  .         6          -0.06386      0.02218916        1.8917
      29          45.51961     6.25128     53.0224  .         7          -0.00862      0.01787509        0.0343
                                                    .         8           0.07398      0.00211882        2.5427
                                                    .         9           0.13057      0.00295757        8.0124
                                                    .        10           0.10068      0.00213170        4.7310
                                                    .        11           0.03096      0.00287401        0.4433
                                                    .        13           0.09630      0.00218262        4.3244
                                                    .        14           0.08752      0.00168840        3.5663
                                                    .        15           0.03881      0.00202292        0.6968
                                                    .        17           0.09671      0.00184999        4.3619
                                                    .        18          -0.11398      0.00194075        6.0811
                                                    .        20          -0.14447      0.00148048        9.8476
                                                    .        23          -0.01845      0.00155593        0.1573
                                                    .        24           0.14857      0.00157032       10.4276
                                                    .        25           0.07392      0.00161697        2.5383
                                                    .        27           0.13770      0.00271251        8.9298
                                                    .        28           0.10559      0.00165733        5.2086
                                                    .        30           0.05977      0.00361783        1.6563
                                                    .        31           0.04208      0.00640323        0.8196
                                                    .        32           0.09043      0.00217542        3.8092
                                                    .        33           0.13536      0.00240979        8.6224
                                                    .        34           0.17141      0.00250685       13.9854
                                                    .        35           0.04779      0.00368678        1.0576
                                                    .        36           0.07590      0.00309978        2.6772
                                                    .        37           0.07688      0.00347955        2.7472
                                                    .        38          -0.01840      0.00517048        0.1565
                                                    .        39          -0.00553      0.00502958        0.0141
                                                    .        40           0.10208      0.00572900        4.8650
                                                    .        41          -0.03994      0.00784267        0.7382
                                                    .        42          -0.07584      0.00995739        2.6730
                                                    .        43          -0.02345      0.02319283        0.2542
                                                    .        44           0.09492      0.01188842        4.2001
                                                    .        45          -0.08108      0.02169088        3.0575
                                                    .        46          -0.04450      0.02361567        0.9167
                                                    .        47          -0.09788      0.02651760        4.4690
                                                    .        48          -0.05971      0.08243269        1.6531
                                                    .        49          -0.08187      0.32896096        3.1174
                                                    .        50          -0.12206      0.45046002        6.9878
```

Figure 4-3 Output From Regression Program (Page 2 of 2)

```
8378-18

NOC= 50          NOE=  2

 1   4200/   0.020000          167772.   00507534     1   4400/   0.0                  0.   00000000
 2           0.020000          167772.   00507534     2           0.0                  0.   00000000
 3           0.020000          167772.   00507534     3           0.0                  0.   00000000
 4           0.020000          167772.   00507534     4           0.0                  0.   00000000
 5           0.020000          167772.   00507534     5           0.0                  0.   00000000
 6           0.020000          167772.   00507534     6           0.0                  0.   00000000
 7           0.020000          167772.   00507534     7           0.0                  0.   00000000
 8           0.020000          167772.   00507534     8           0.0                  0.   00000000
 9           0.020000          167772.   00507534     9           0.0                  0.   00000000
10           0.020000          167772.   00507534    10           0.0                  0.   00000000
11           0.020000          167772.   00507534    11           0.0                  0.   00000000
12           0.020000          167772.   00507534    12          36.788300      753424.   02677420
13           0.020000          167772.   00507534    13           0.0                  0.   00000000
14           0.020000          167772.   00507534    14           0.0                  0.   00000000
15           0.020000          167772.   00507534    15           0.0                  0.   00000000
16           0.020000          167772.   00507534    16          31.852280      652335.   02372056
17           0.020000          167772.   00507534    17           0.0                  0.   00000000
18           0.020000          167772.   00507534    18           0.0                  0.   00000000
19           0.020000          167772.   00507534    19         -37.629268    -1794647.   71116651
20           0.020000          167772.   00507534    20           0.0                  0.   00000000
21           0.020000          167772.   00507534    21         -34.113388     -698642.   75253356
22           0.020000          167772.   00507534    22         -38.446289     -787380.   74776114
23           0.020000          167772.   00507534    23           0.0                  0.   00000000
24           0.020000          167772.   00507534    24           0.0                  0.   00000000
25           0.020000          167772.   00507534    25           0.0                  0.   00000000
26           0.020000          167772.   00507534    26          48.860916     1000672.   03642337
27           0.020000          167772.   00507534    27           0.0                  0.   00000000
28           0.020000          167772.   00507534    28           0.0                  0.   00000000
29           0.020000          167772.   00507534    29          45.519608      932242.   03434621
30           0.020000          167772.   00507534    30           0.0                  0.   00000000
31           0.020000          167772.   00507534    31           0.0                  0.   00000000
32           0.020000          167772.   00507534    32           0.0                  0.   00000000
33           0.020000          167772.   00507534    33           0.0                  0.   00000000
34           0.020000          167772.   00507534    34           0.0                  0.   00000000
35           0.020000          167772.   00507534    35           0.0                  0.   00000000
36           0.020000          167772.   00507534    36           0.0                  0.   00000000
37           0.020000          167772.   00507534    37           0.0                  0.   00000000
38           0.020000          167772.   00507534    38           0.0                  0.   00000000
39           0.020000          167772.   00507534    39           0.0                  0.   00000000
40           0.020000          167772.   00507534    40           0.0                  0.   00000000
41           0.020000          167772.   00507534    41           0.0                  0.   00000000
42           0.020000          167772.   00507534    42           0.0                  0.   00000000
43           0.020000          167772.   00507534    43           0.0                  0.   00000000
44           0.020000          167772.   00507534    44           0.0                  0.   00000000
45           0.020000          167772.   00507534    45           0.0                  0.   00000000
46           0.020000          167772.   00507534    46           0.0                  0.   00000000
47           0.020000          167772.   00507534    47           0.0                  0.   00000000
48           0.020000          167772.   00507534    48           0.0                  0.   00000000
49           0.020000          167772.   00507534    49           0.0                  0.   00000000
50           0.020000          167772.   00507534    50           0.0                  0.   00000000
```

Figure 4-4 Output From Coefficient Converter Program

SECTION 5

CALCULATION AND MEASUREMENT OF INSTRUMENT SIGNAL AND NOISE

5.1 ACTIVE SIGNAL

The radiant power P reaching the main infrared detector when the filter wheel is at a given wavelength (9.5 μm, for example) is given by the following formula for the system in operation with the remote active transmitter unit:

$$P = L_\lambda \Delta_\lambda \frac{A_t A_r}{R^2} \tau \qquad (5\text{-}1)$$

where

L_λ = the spectral radiance of the source at 9.5 μm. For a source temperature of 1265°C (1538°K), a blackbody L_λ is 0.092 W/(cm^2-sr-μm). With an emissivity of about 0.8, the L_λ is 0.073 W/(cm^2-sr-μm).

Δ_λ = the spectral bandwidth of a small area of the filter wheel for collimated rays. For the filter wheel in the ozone monitor, this bandwidth is 0.085 μm.

A_t = the area of the transmitter optics. The transmitter primary mirror diameter is 31.7 cm (12.5 in.) and the obscuring secondary mirror diameter is 14 cm (5.5 in.). A_t = 635 cm^2.

A_r = the area of the receiver optics. The receiver primary mirror diameter is 26.6 cm (10.5 in.) and the secondary mirror diameter is 15.0 cm (5.94 in.). A_r = 378 cm^2.

R = the range between the transmitter and the receiver. It is nominally 1.61 km at maximum range.

τ = the transmittance of the optical system including the atmospheric path and the chopper. There are six mirrors, each with a reflectance of perhaps 0.92 (allowing for a little dirt). The beam splitter has a transmittance of 0.92. The chopper has an optical efficiency at the fundamental chopping frequency of about 0.39. The uncoated IRTRAN-2 window has a transmittance of about 0.7. The transmittance of the atmosphere is perhaps 0.8. The transmittance of the filter wheel is 0.6 at 9.5 μm.

$$\tau = 0.92^6 \times 0.92 \times 0.39 \times 0.7 \times 0.8 \times 0.6 = 0.075$$

$$P = 0.073 \frac{W}{cm^2\text{-sr-}\mu m} \times 0.085\ \mu m \times \frac{635\ cm^2 \times 378\ cm^2}{1.61^2 \times 10^{10}\ cm^2} \times 0.075$$

$$= 4.3 \times 10^{-9}\ W\ rms$$

This radiant power falling on the photoconductive infrared detector produces a change in electrical conductance which with the constant bias voltage produces a change in the electrical current through the detector. This current passes into the preamplifier which acts as a transresistance to produce an output voltage V proportional to the input current.

$$V = P \times Resp. \times E_{bias} \times R_T \qquad (5\text{-}2)$$

where

P = the chopped radiant power reaching the detector calculated, for example, from Equation 5-1

Resp. = the infrared detector responsivity for 9.5 μ radiant power in mhos/watt and was measured to be 45×10^{-3} mho/W for the detector delivered with the Ozone Monitor

E_{bias} = the bias voltage, which is set at 5.8 V to maximize the S/N ratio in the output of the detector currently installed

R_T = the transresistance of the preamplifier and is 66.8 MΩ.

$$V = 4.3 \times 10^{-9}\ W \times 45 \times 10^{-3} \frac{mho}{W} \times 5.8\ V \times 66.8 \times 10^6\ \Omega$$

$$= 0.075\ V$$

The output of the preamplifier is filtered, amplified, rectified, integrated, and converted into a digital signal D.

$$D = V \times 0.4 \times 2^k \times 2\sqrt{2}/\pi \times 1/480 \times 1/(RC) \times 410 \qquad (5\text{-}3)$$

where

0.4 = the insertion loss of the bandpass filter and associated impedance matching voltage divider.

2^k = the gain of the computer controlled variable gain amplifier, where k is equal to the software variable "AGC"

$2\sqrt{2}/\pi$ = conversion from the rms voltage of the AC signal to the average value of the rectified DC signal

$1/480$ = the analog integration time in seconds

R = the input resistance to the integrator, which is $22.1 \times 10^3 \Omega$

C = the feedback capacitance of the integrator, which is 0.022×10^{-6} F

410 units/V = the scaling of the 12-bit A/D convertor which covers an input range of 10 V in 4096 units.

$$D = \frac{7.5 \times 10^{-2} \times 0.4 \times 2^k \times 2\sqrt{2}/\pi \times 410}{480 \times 22.1 \times 10^3 \times 0.022 \times 10^{-6}} = 47.6 \times 2^k$$

The Ozone Monitor computer program sums 64 such A/D converter readings, amounting to a dwell time of 0.133 sec for each channel. This sum is divided by the gain that was introduced by the range control variable amplifier. For scaling purposes, this number is further divided by 32 if the channel reading is to be output on the Teletype, or by 2 if the readings are punched by the high-speed punch. In the latter case, the off-line HEXED program that processes the high-speed punch output divides by 16 so that the processed high-speed punch readings are equal to the Teletype readings. Thus, the channel reading in Teletype units (T.t.u.) is:

$$\begin{aligned} \text{T.t.u.} &= D \times 64 \times 1/2^k \times 1/32 \\ \text{T.t.u.} &= 47.6 \times 2^k \times 1/2^k \times 2 \approx 100 \end{aligned} \tag{5-4}$$

The actual signals at 1.6 km (1 mile) range at 9.5-μm wavelength that were measured in Ann Arbor varied from 80 to 125, depending on the visibility and presumably on the accuracy of pointing the receiver and the transmitter units. This is considered to be in good agreement with the calculated estimate of 100.

5.2 PASSIVE SIGNAL

When the instrument is operated in the passive mode, the radiant power reaching the main infrared detector when the filter wheel is at, say 9.5 μm, is given by:

$$P = L_\lambda \Delta_\lambda \Omega A_r \tau \tag{5-5}$$

where

L_λ = the difference between the spectral radiance of a source which is large enough to fill the instrument's FOV and the spectral radiance of the grooved internal chopper which is assumed to be close to the local ambient temperature. If the chopper temperature is 295°K and the source has an effective radiation temperature 10° warmer or 305°K, the spectral radiance difference at 9.5 μm is 1.68×10^{-4} W/(sr-μm-cm^2).

Ω = the solid angle of the instrument's FOV and equal to $A_d/(\text{f. l.})^2$, where A_d is the detector area and f. l. is the receiver focal length. $0.785 \times 10^{-2}\ \text{cm}^2/40^2\ \text{cm}^2 = 4.9 \times 10^{-6}$ sr

τ = $0.92^4 \times 0.92 \times 0.39 \times 0.7 \times 0.6 = 0.108$

$$P = 1.68 \times 10^{-4} \frac{\text{W}}{\text{cm}^2\text{-sr-}\mu\text{m}} \times 0.085\ \mu \times 4.9 \times 10^{-6}\ \text{sr} \times 378\ \text{cm}^2 \times 0.108$$

$$= 2.8 \times 10^{-9}\ \text{W rms}$$

Using this power and Equations 5-2, 5-3, and 5-4, a signal of 65 units would be predicted or 6.5 units/degree. Measurement of hot and cold black-painted tanks gave a responsivity of about 5 units/degree.

Before instrument delivery, instrument alignment was performed only to maximize the signal from a 400-m-distant transmitter. Instrument performance with extended sources could probably be improved somewhat by realigning and optimizing the detector position for an extended area source.

5.3 NOISE

The detector noise at the preamplifier output was 0.60 mV as measured with a 6-Hz bandwidth centered at 480 Hz. The noise of the preamplifier itself, with a 600-kΩ resistor in place of the detector, is much less, 0.07 mV. The noise bandwidth, BW, of the Ozone Monitor is:

$$BW = \frac{1}{2T} = \frac{1}{2 \times 0.133 \text{ sec}} = 3.8 \text{ Hz}$$

where T is the integration time per channel. The detector noise in this 3.8-Hz bandwidth would be:

$$0.60 \text{ mV} \times \sqrt{\frac{3.8}{6}} = 0.48 \text{ mV rms}$$

If the output noise were entirely due to detector noise (which is the optimum situation), the output noise would be given by Equations 5-3 and 5-4 operating on this voltage. The result is 0.64 Teletype units of noise. The actual measured noise (standard deviation from the mean of the channel readings) with the beam blocked is 1.2 Teletype units. This includes all noise sources in the receiver unit. A typical measured noise on a sunny day is 5 units which includes atmospheric effects such as scintillation, pointing effects due to vibration and wind loading, source fluctuations, and all other noise sources.

BLANK PAGE

SECTION 6

RESULTS

6.1 INSTRUMENT RESPONSE

Figure 6-1 shows the signal spectrum received from the transmitter when the transmitter was about a meter away from the receiver. This spectrum at essentially zero range is the response curve of the instrument and includes the source spectrum, the varying filter wheel transmittance with wheel position, and the infrared detector response, as well as atmospheric absorption in the meter or two of air in the optical path. The beam was attenuated with a pierced sheet of aluminum foil so as to reduce the optical signal to normal levels. The spectrum shown is the average of 39 consecutive spectra.

6.2 ACTIVE-MODE SPECTRA

Figure 6-2 shows, on the left, average single-beam spectra as obtained by the Ozone Monitor. About 30 to 60 spectra are included in each average. The path length varies from 0.42 to 1.67 km. On the right are shown the corresponding normalized spectra obtained by dividing the single-beam spectra by the instrument response curve shown in Figure 6-1 and arbitrarily normalizing the peak to 100.

Each individual spectrum was gathered in about 8.5 sec, which includes about 2 sec for moving the filter wheel and a dwell time of 0.133 sec at each of 50 channels.

Figure 6-3 shows two examples of digital listings of typical mean spectra.

Figure 6-4 shows a spectrum taken with a sheet of 30μm polystyrene film in a 420-m-long beam. Also shown for comparison are the wavelengths where polystyrene has absorption bands.

Figure 6-5 shows spectra with a 1-m-long gas cell in the 1.67-km path length beam. The gas cell diameter was larger than that of the Ozone Monitor optical elements and had polyethylene film windows. Ozone was introduced into the cell from an ozone generator. In this figure, the spectrum peak has been arbitrarily normalized to 75 to suggest the attenuation caused by the two polyethylene windows. The ozone measurements shown were made using a spectrometric potassium iodide oxidation method and were made by Dr. Harold M. Barnes, Jr., of the National

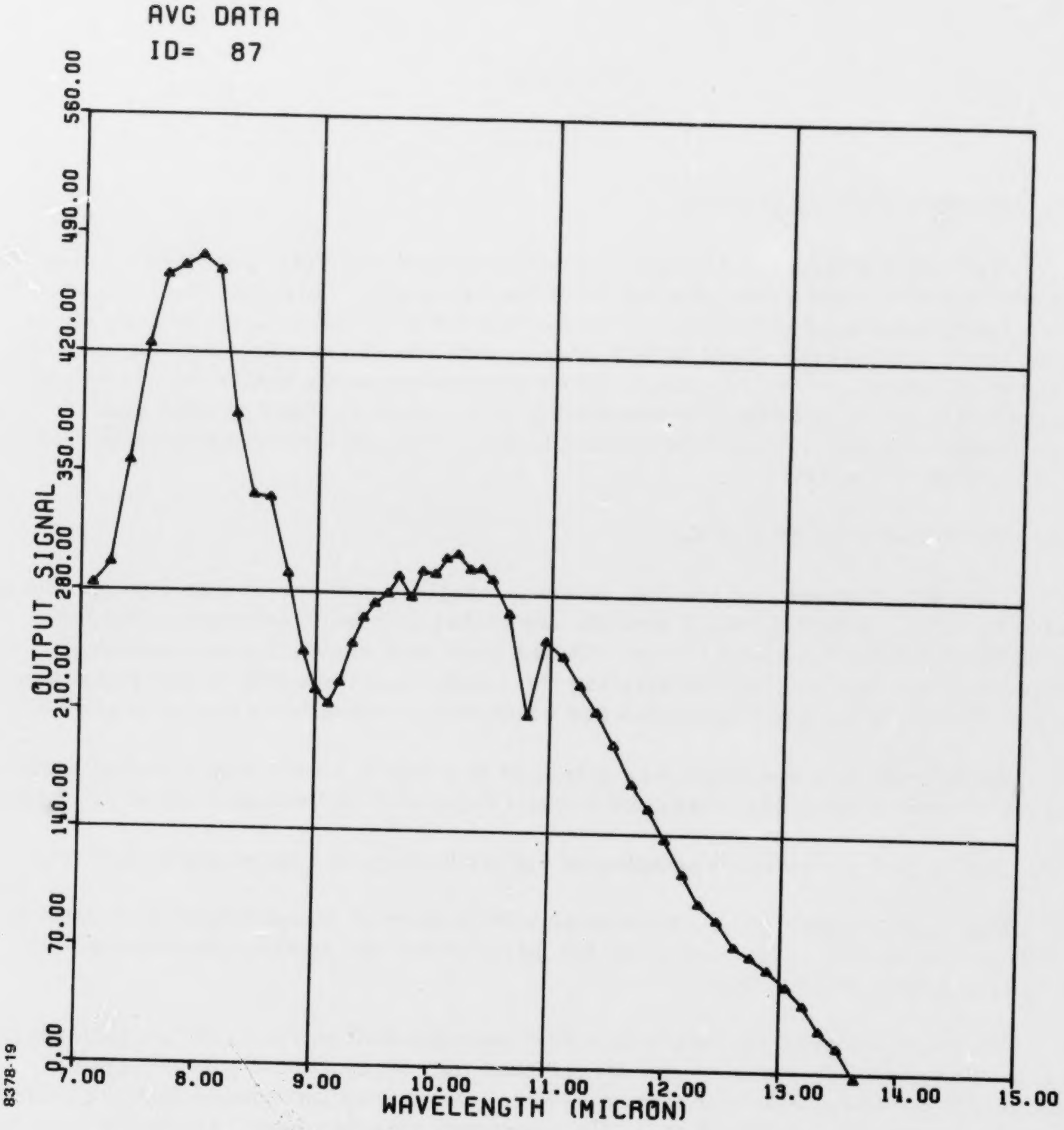


Figure 6-1 Response Curve of Instrument with Transmitter

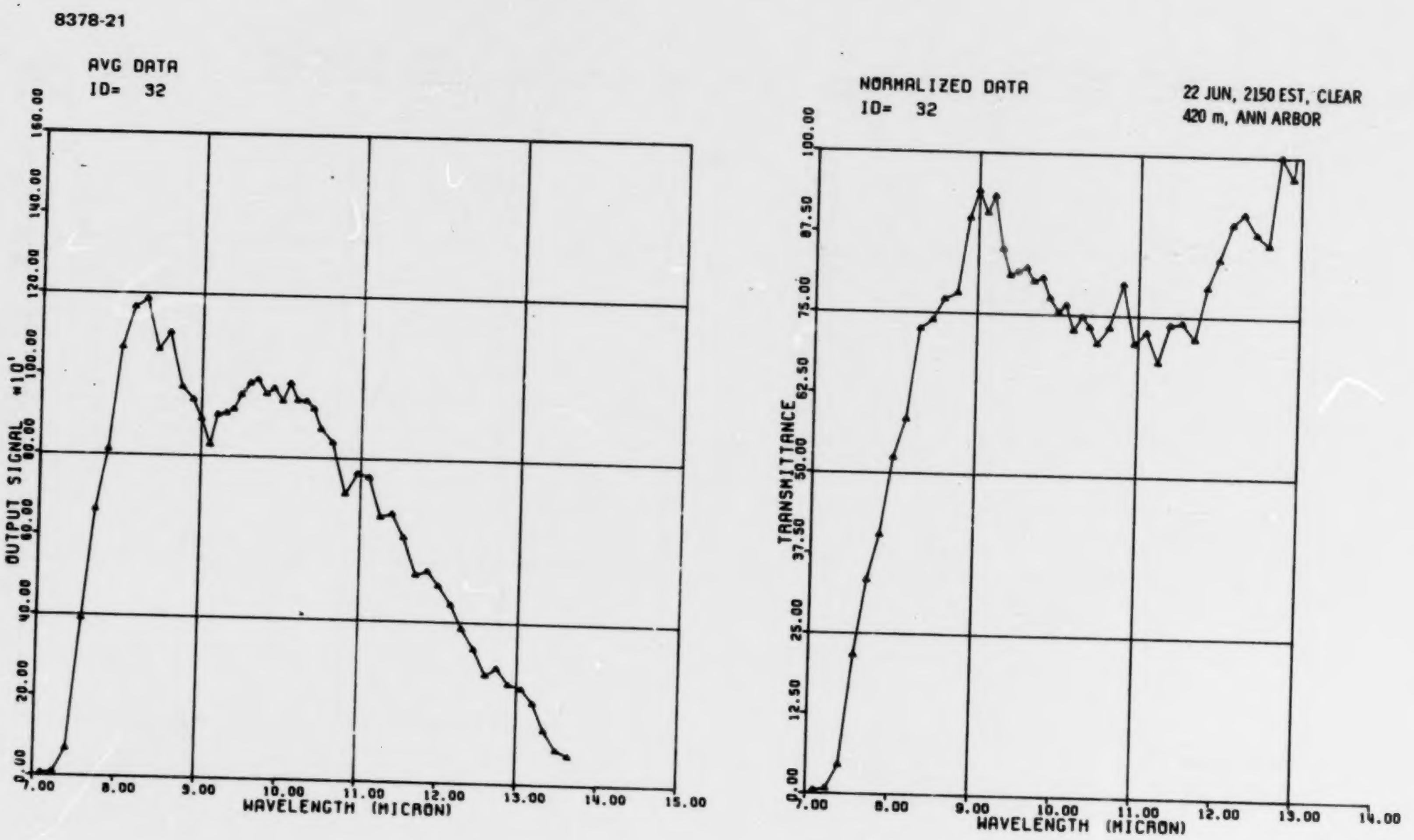


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 1 of 10)

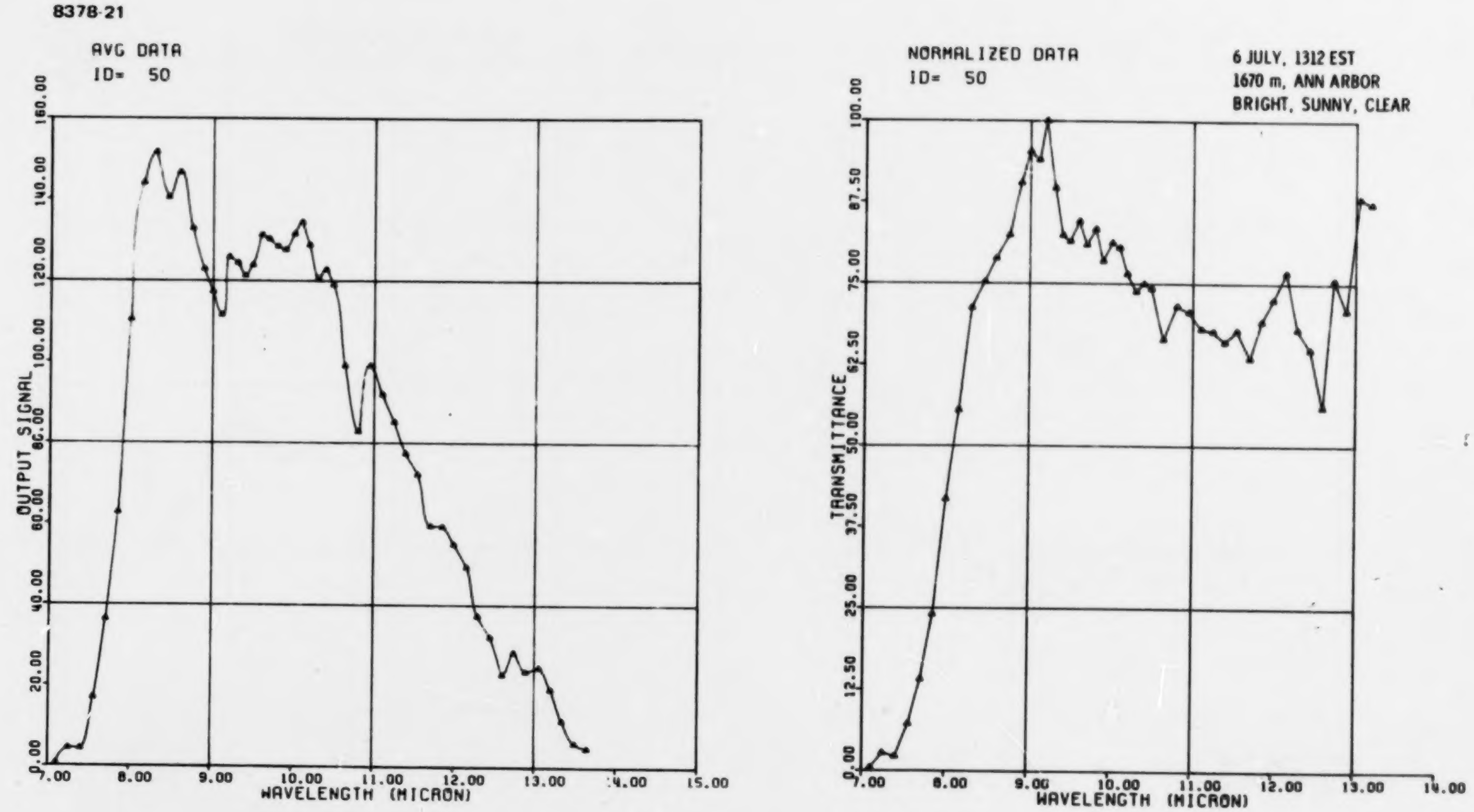


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 2 of 10)

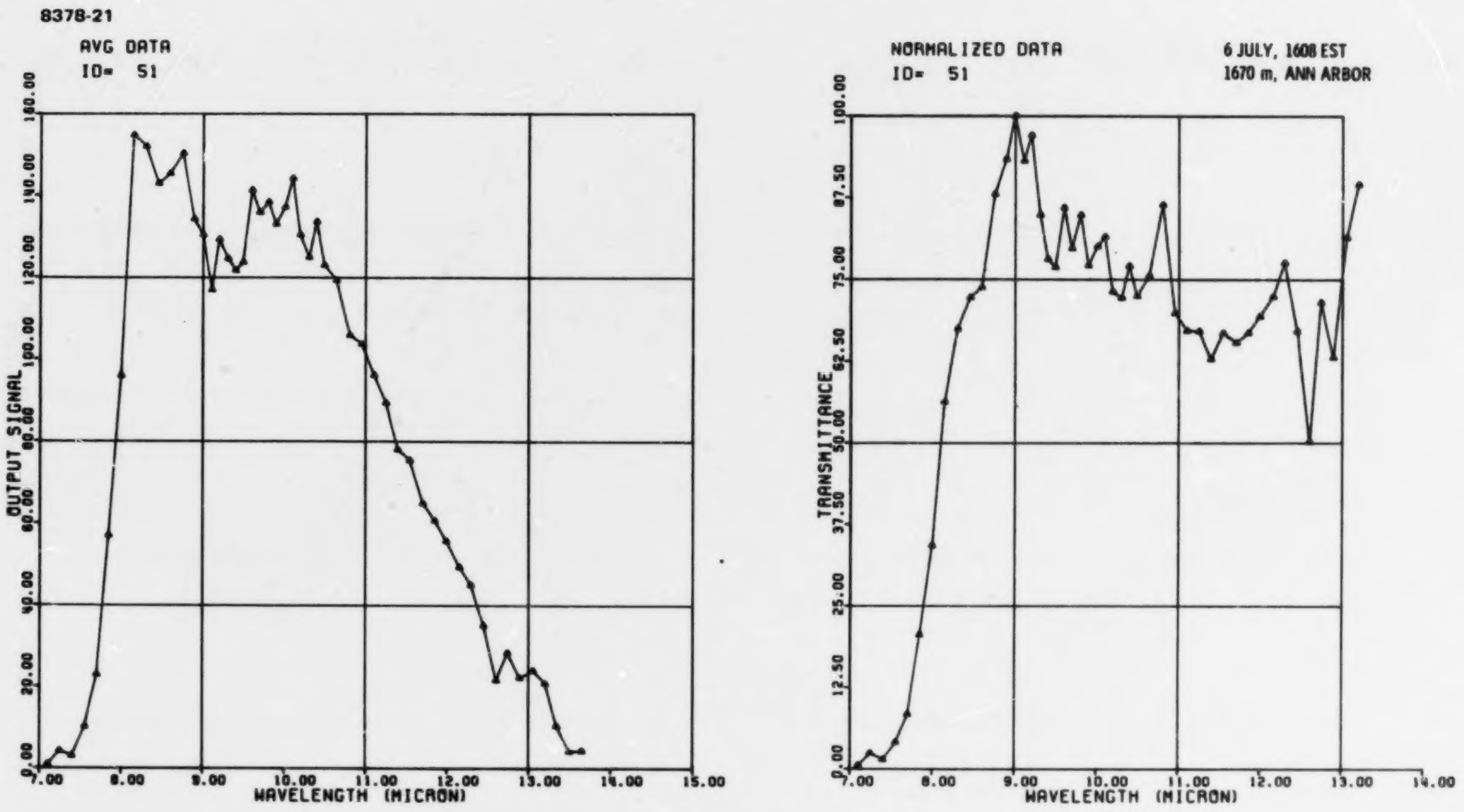


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 3 of 10)

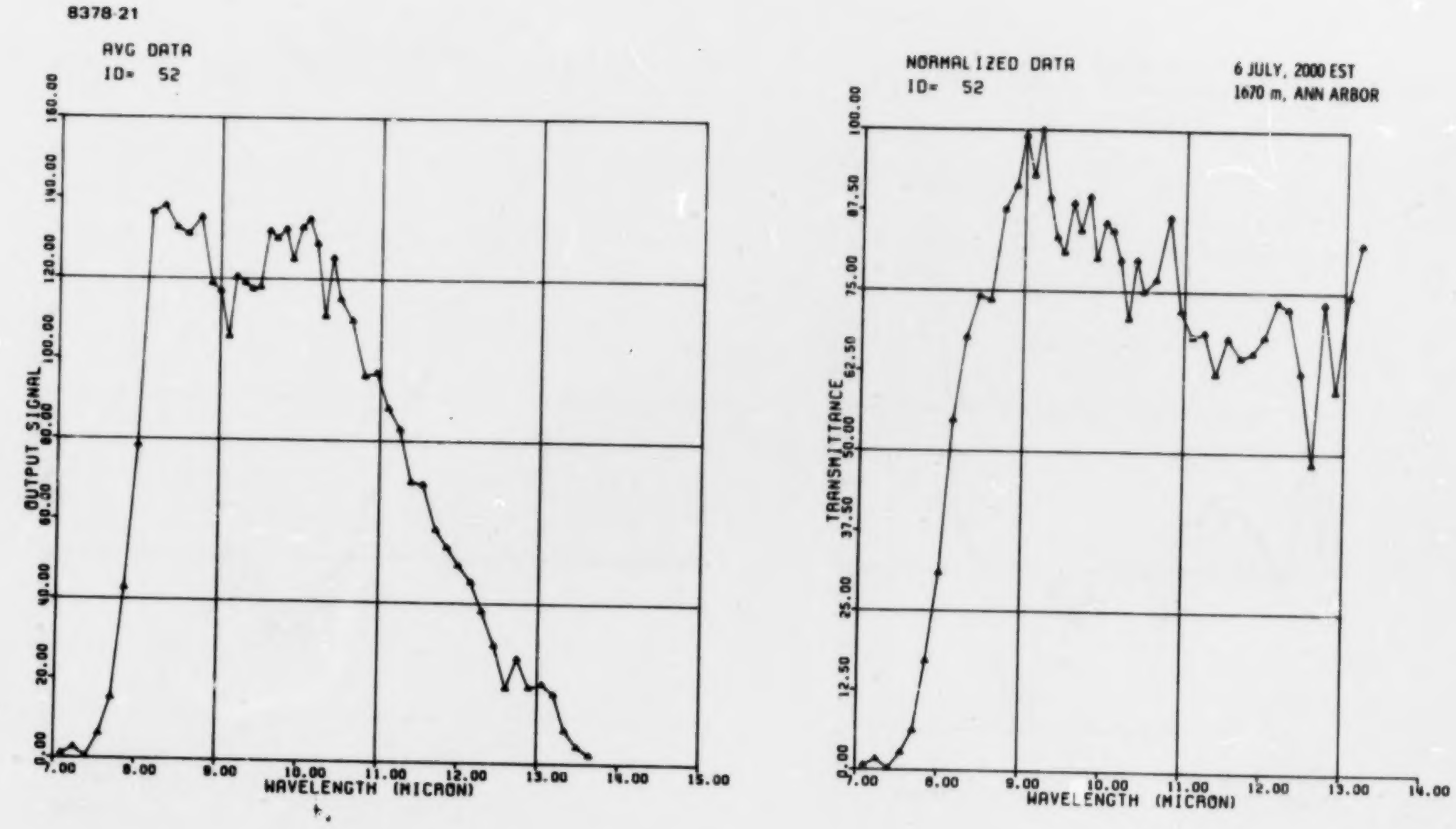


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 4 of 10)

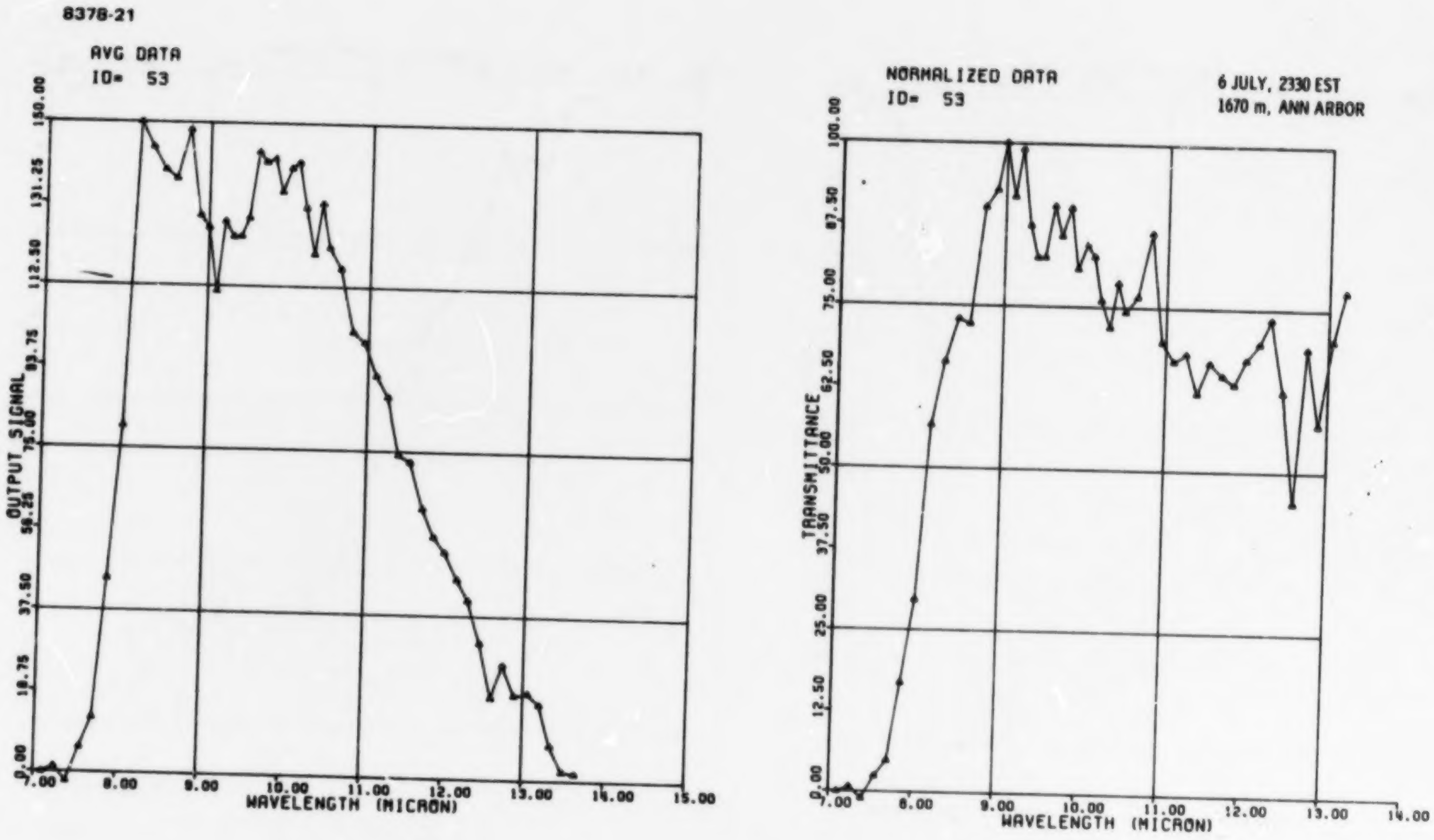


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 5 of 10)

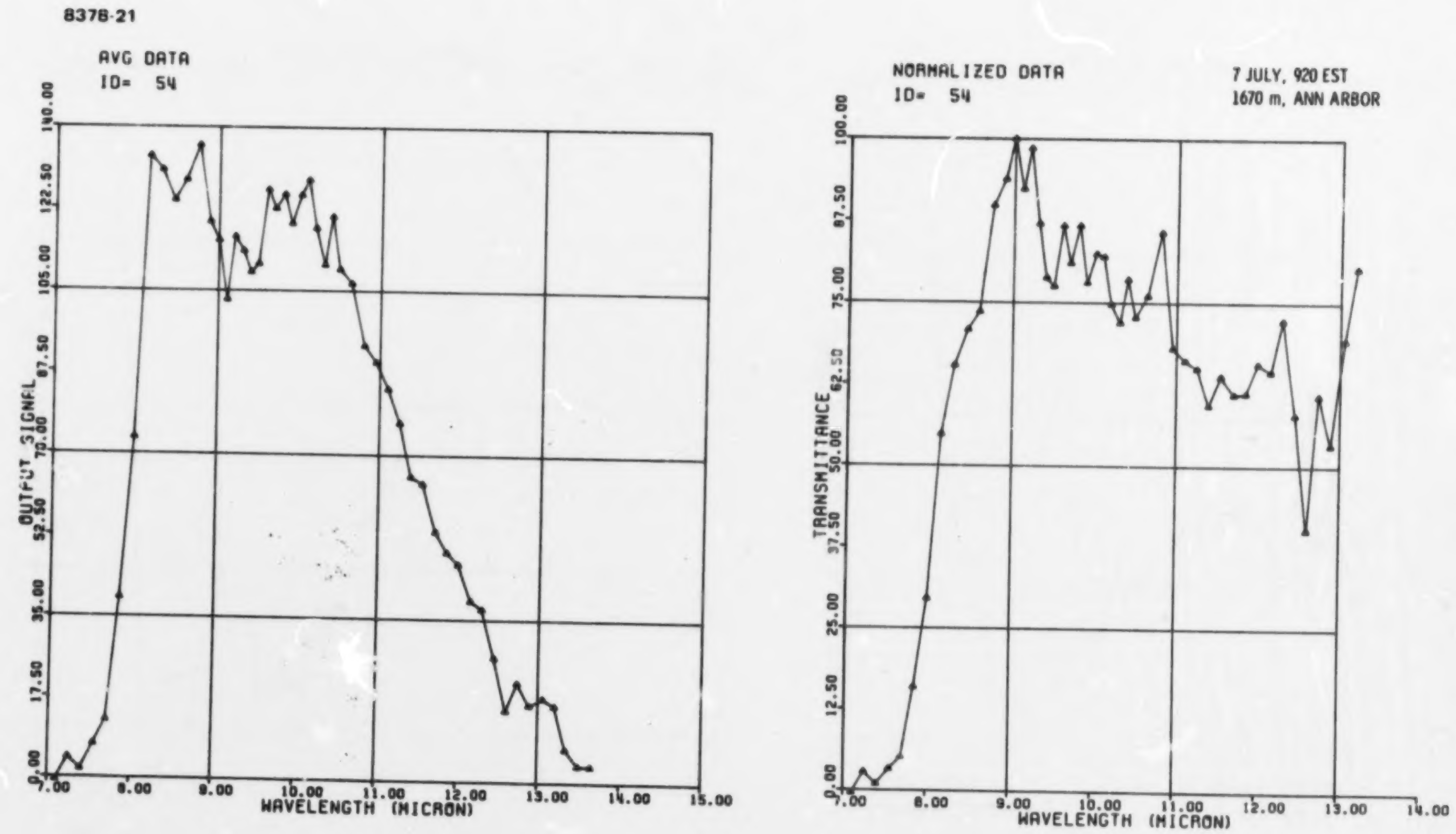


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 6 of 10)

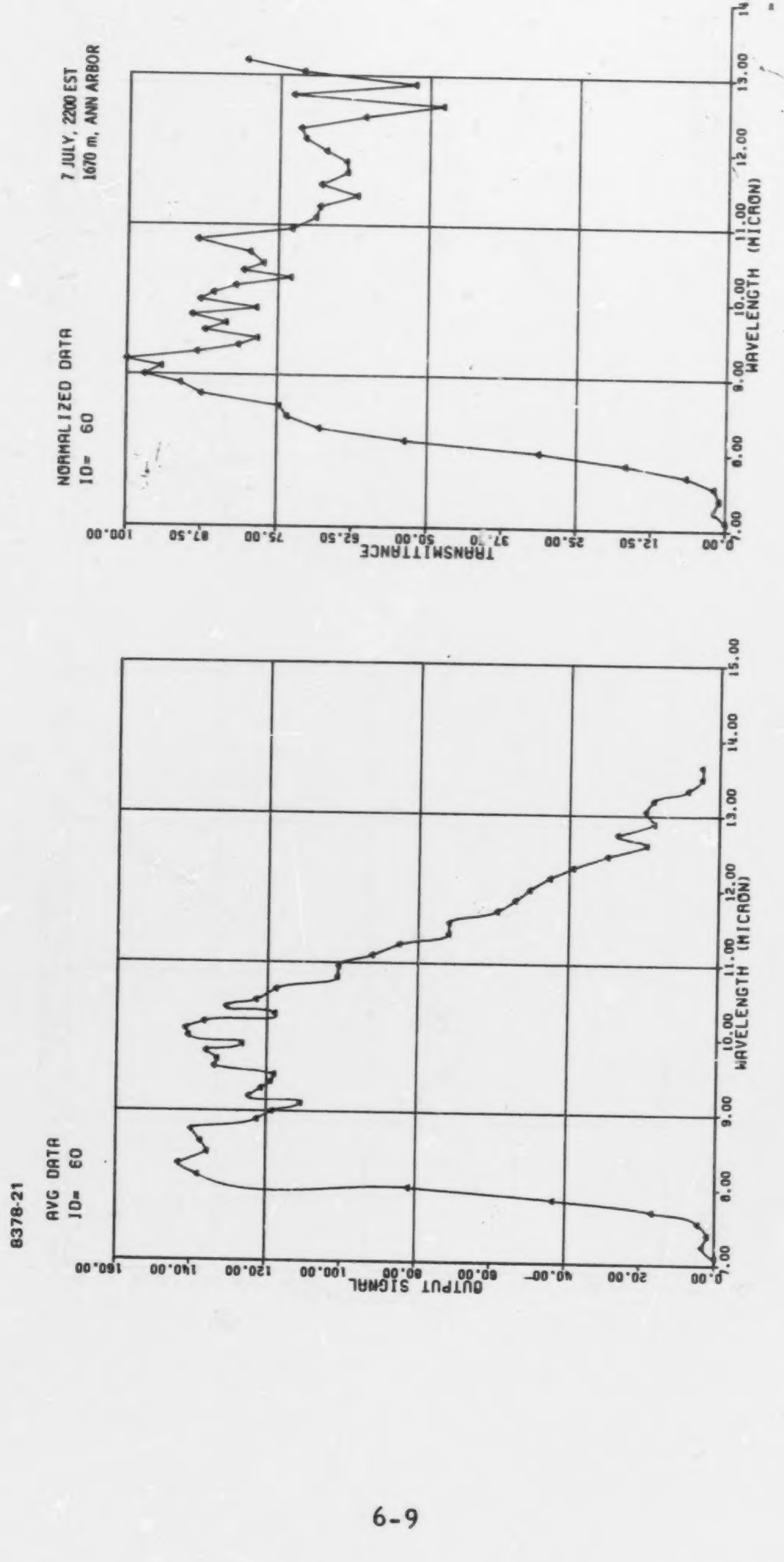


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 7 of 10)

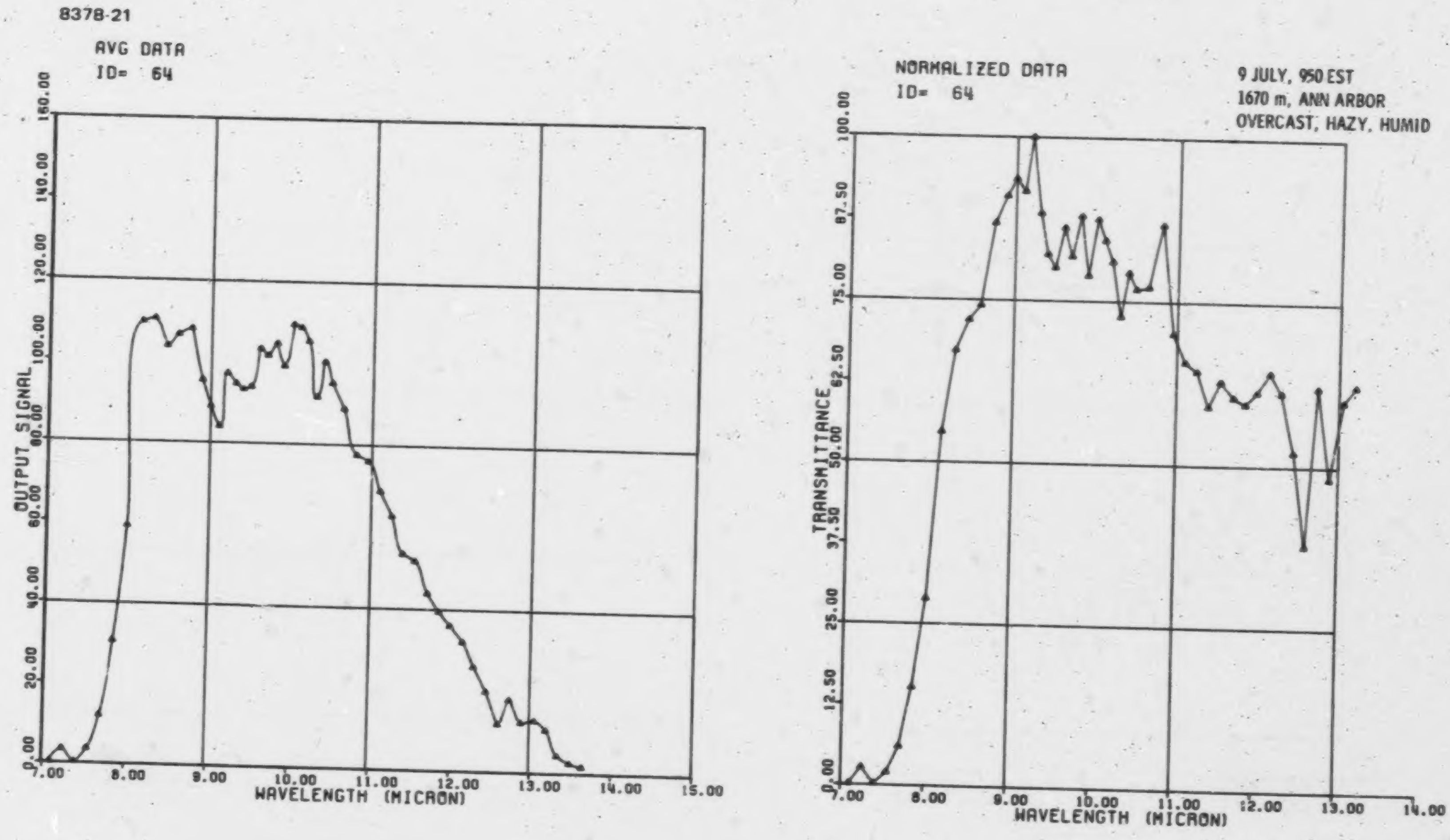


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 8 of 10)

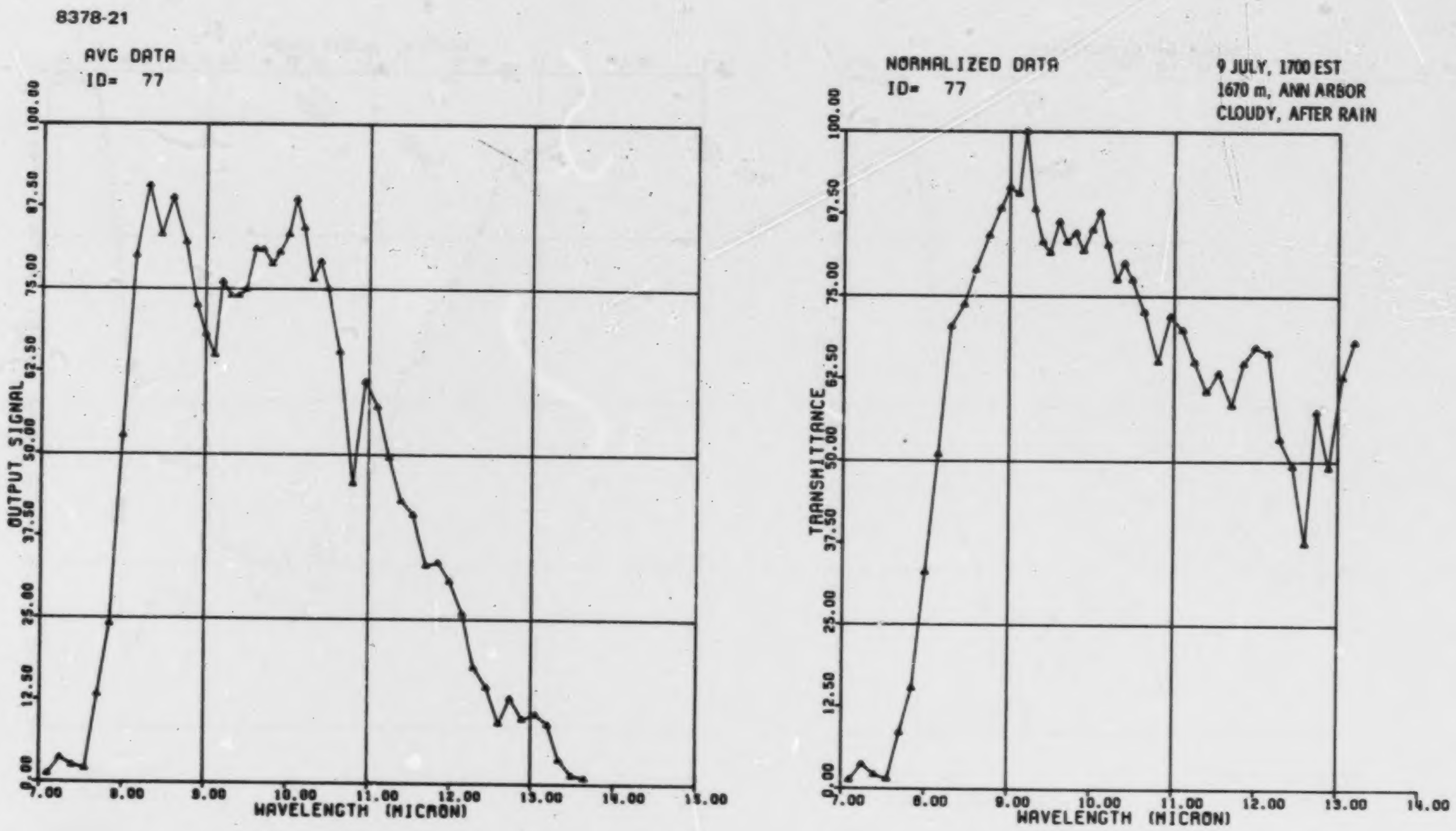


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 9 of 10)

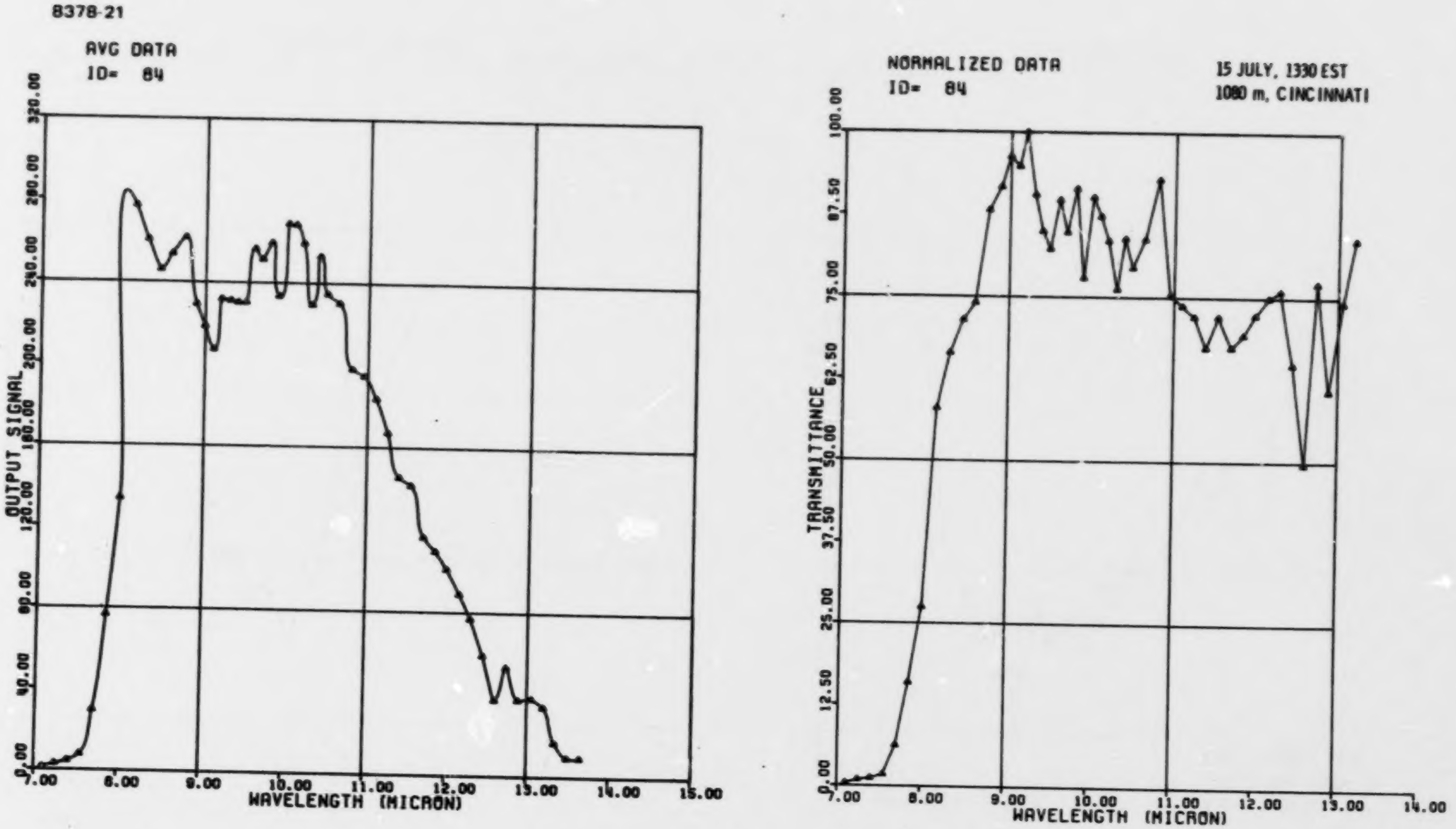


Figure 6-2 Spectra Obtained With Ozone Monitor
(Page 10 of 10)

8378-22

```
NUMBER OF CHANNELS:        50
NUMBER OF CASES:        57
ID NUMBER:        60

CHANNEL          MEAN               STD DEV
NUMBER

    1          -0.07127             2.93848
    2           3.36952             2.93682
    3           1.99890             3.02428
    4           4.50110             3.65923
    5          16.78947             3.24084
    6          43.24671             3.26397
    7          81.80373             4.16710
    8         138.14912             4.54918
    9         143.28618             4.60900
   10         135.61732             3.84667
   11         137.38816             4.66624
   12         139.88487             4.95977
   13         122.41776             4.31493
   14         118.39583             4.23038
   15         110.75768             4.16713
   16         124.60307             4.08316
   17         121.33224             3.84872
   18         118.72917             3.71371
   19         117.87939             3.65566
   20         133.90899             4.04578
   21         133.15351             3.74710
   22         136.15461             3.90491
   23         126.51316             3.92982
   24         140.90899             4.46961
   25         141.65461             4.96258
   26         136.74561             4.60327
   27         117.89583             3.89141
   28         130.89035             4.84112
   29         122.87061             4.34677
   30         117.57895             3.90378
   31         101.30921             3.71298
   32         101.04605             4.31325
   33          92.09320             3.96050
   34          84.92873             3.26750
   35          71.86732             3.50341
   36          71.73794             3.38028
   37          59.00548             3.41895
   38          54.17544             3.48303
   39          50.36842             3.84503
   40          44.99452             2.71280
   41          38.76535             2.67027
   42          29.65899             3.27970
   43          19.25000             2.33274
   44          26.98355             3.09710
   45          17.28070             2.61126
   46          19.58443             3.40476
   47          17.50110             2.91609
   48           8.33333             3.15988
   49           4.65570             3.21207
   50           4.63377             2.97200
```

```
NUMBER OF CHANNELS:        50
NUMBER OF CASES:        25
ID NUMBER:        79

CHANNEL          MEAN               STD DEV
NUMBER

    1          -0.69250             1.71694
    2           3.74750             2.53353
    3           1.83750             2.57138
    4           1.56000             2.15870
    5          11.28750             2.90743
    6          15.97000             2.51047
    7          34.23250             2.31535
    8          54.55500             2.81703
    9          59.15250             2.24486
   10          55.07750             2.41767
   11          56.85500             2.70065
   12          51.17000             2.39978
   13          45.24750             2.04502
   14          40.55500             2.30696
   15          38.21500             2.10531
   16          43.99500             2.42404
   17          41.70250             2.57936
   18          27.07000             1.82131
   19          17.51500             1.81764
   20          30.63250             2.83454
   21          25.81250             2.34555
   22          26.98000             1.98437
   23          36.10750             2.38986
   24          48.17250             1.89368
   25          56.97250             2.52301
   26          57.04750             2.46785
   27          53.44250             1.81124
   28          54.80750             1.79090
   29          52.88000             2.05847
   30          47.05000             2.27375
   31          35.73750             4.38455
   32          43.23750             3.01450
   33          41.07500             1.52571
   34          35.31750             1.88857
   35          31.40000             2.90182
   36          30.02000             1.60085
   37          25.36750             2.14310
   38          24.70250             2.65222
   39          23.33000             2.91690
   40          19.89250             2.03745
   41          14.75500             2.36214
   42          11.31000             2.54001
   43           8.27500             2.36125
   44          10.27500             1.76804
   45           7.49000             2.17688
   46           8.47250             3.01197
   47           7.37500             2.16333
   48           3.72750             2.44070
   49           2.45500             2.12305
   50           1.07500             1.43852
```

Figure 6-3 Mean Spectra for ID 60 and 79

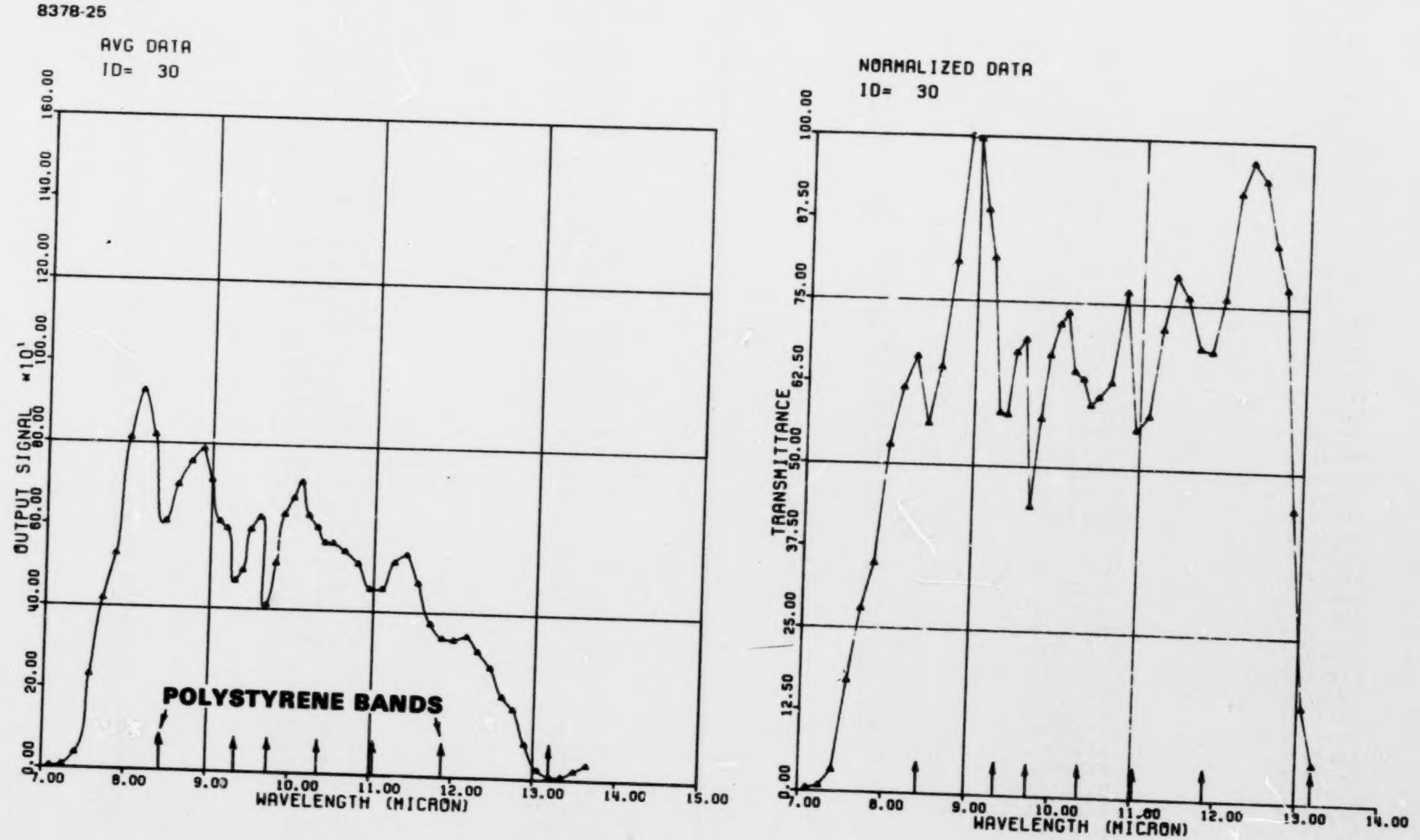


Figure 6-4 Polystyrene Spectra

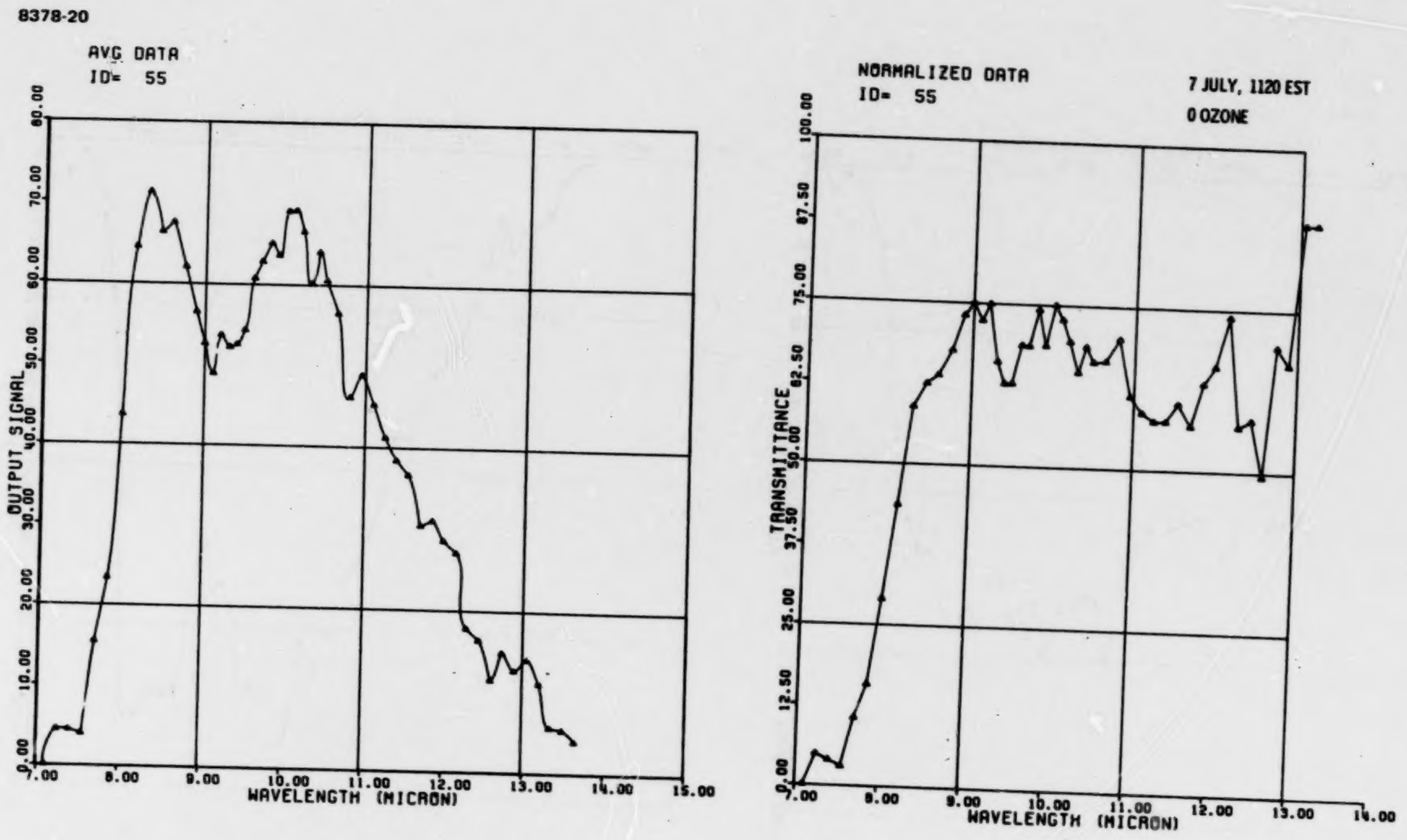
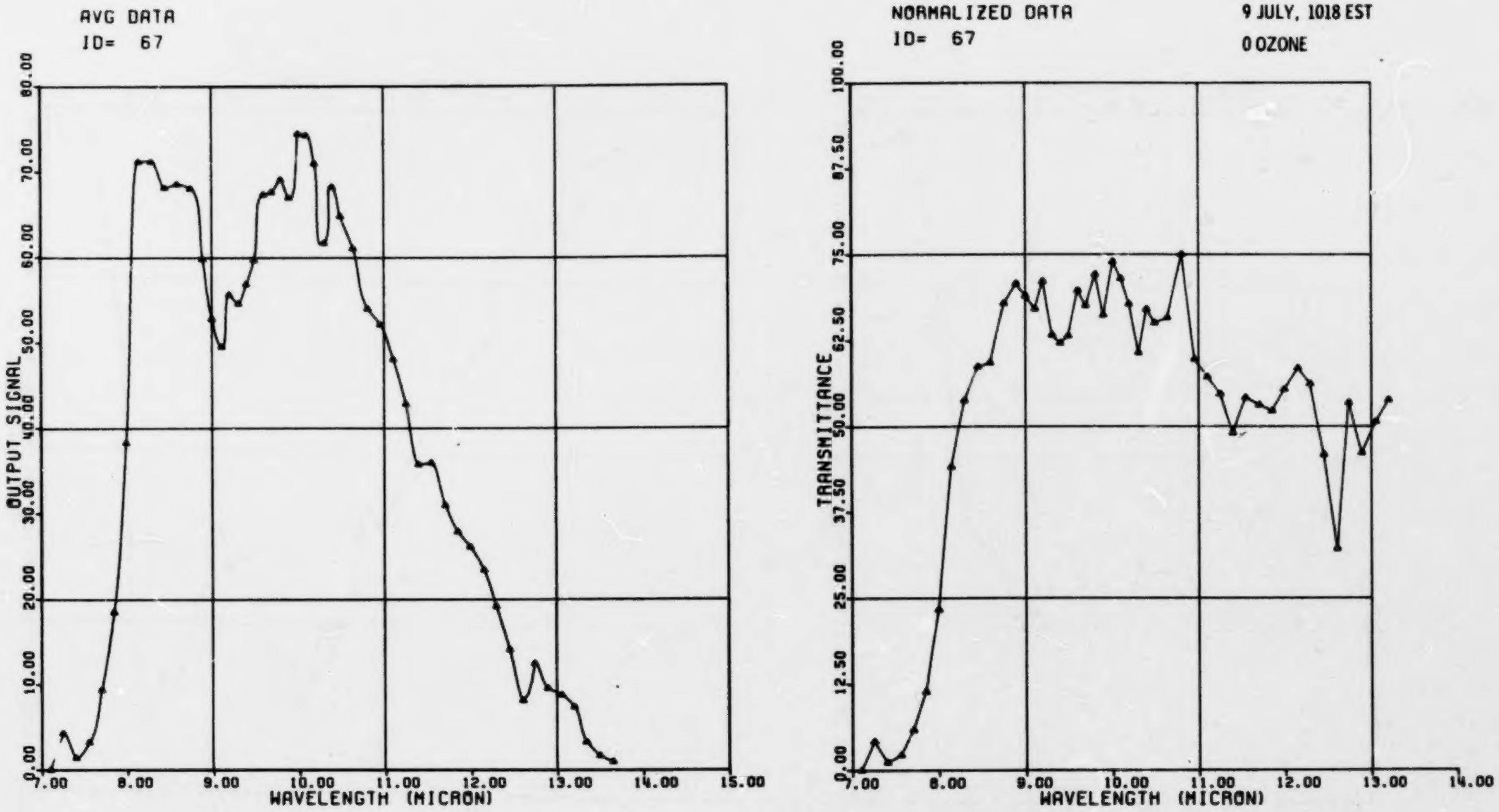


Figure 6-5 Spectra with Ozone Cell in Beam (Page 1 of 7)

8378-20



AVG DATA
ID= 67

NORMALIZED DATA
ID= 67

9 JULY, 1018 EST
0 OZONE

Figure 6-5 Spectra with Ozone Cell in Beam (Page 2 of 7)

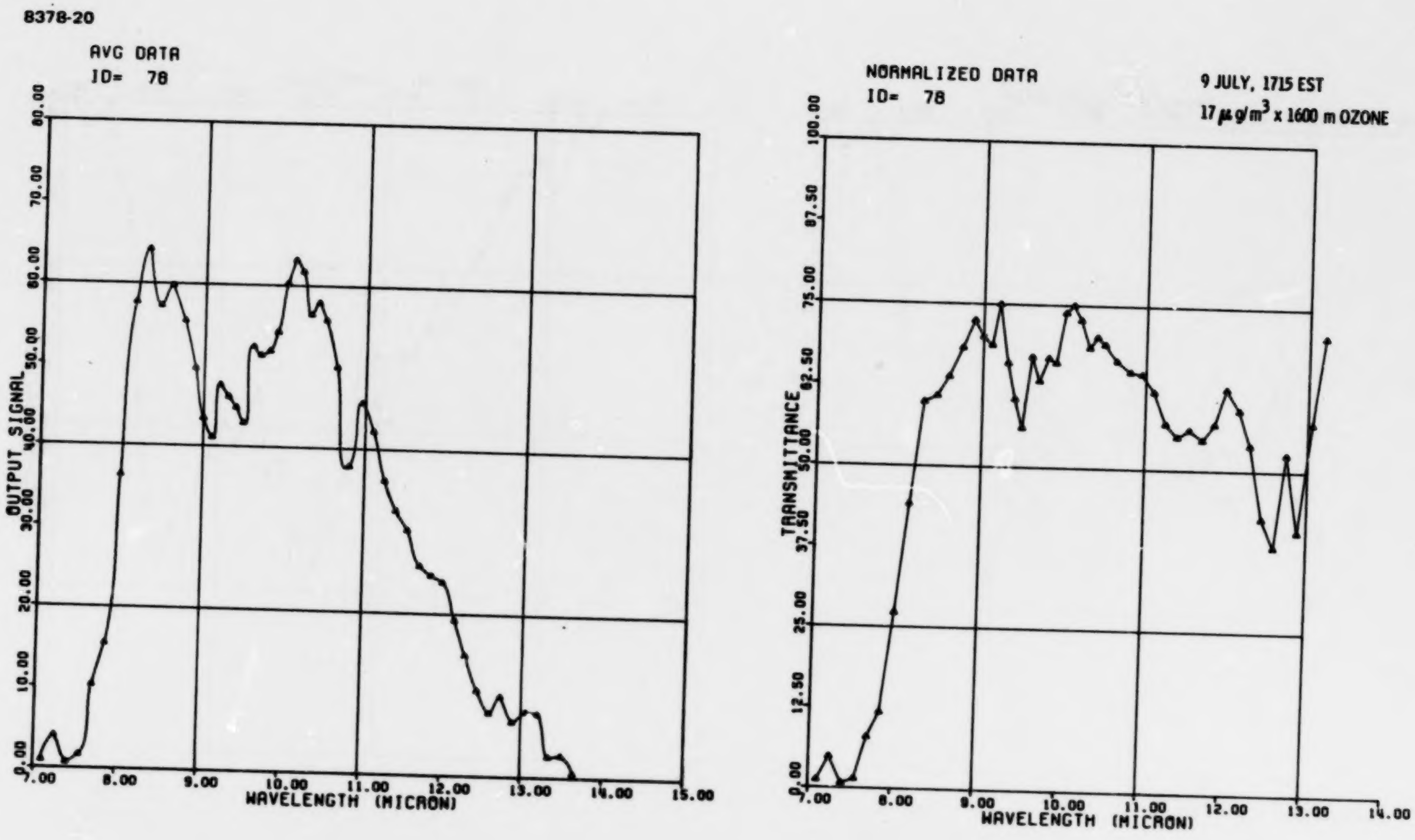


Figure 6-5 Spectra with Ozone Cell in Beam (Page 3 of 7)

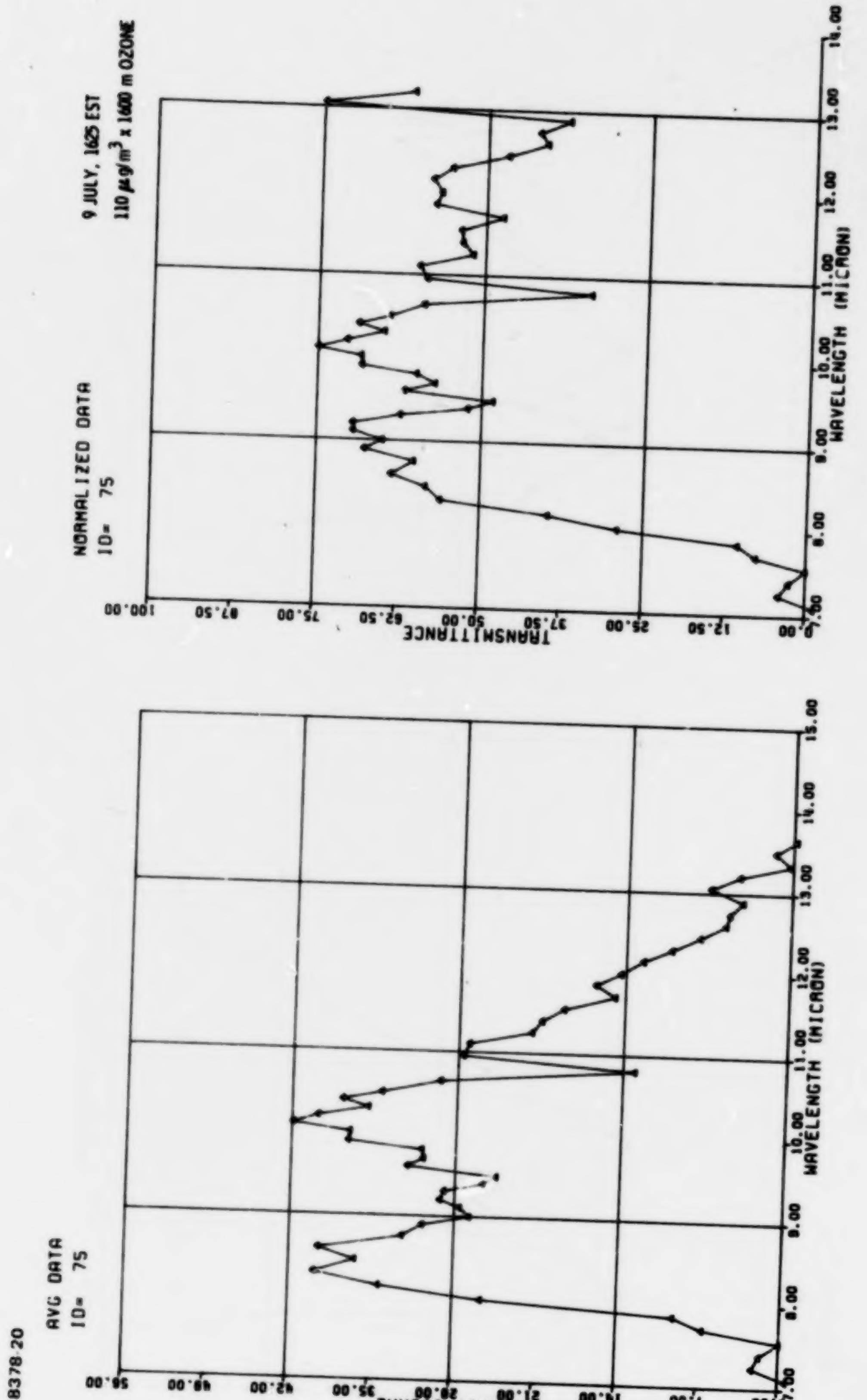


Figure 6-5 Spectra with Ozone Cell in Beam (Page 4 of 7)

8378-20

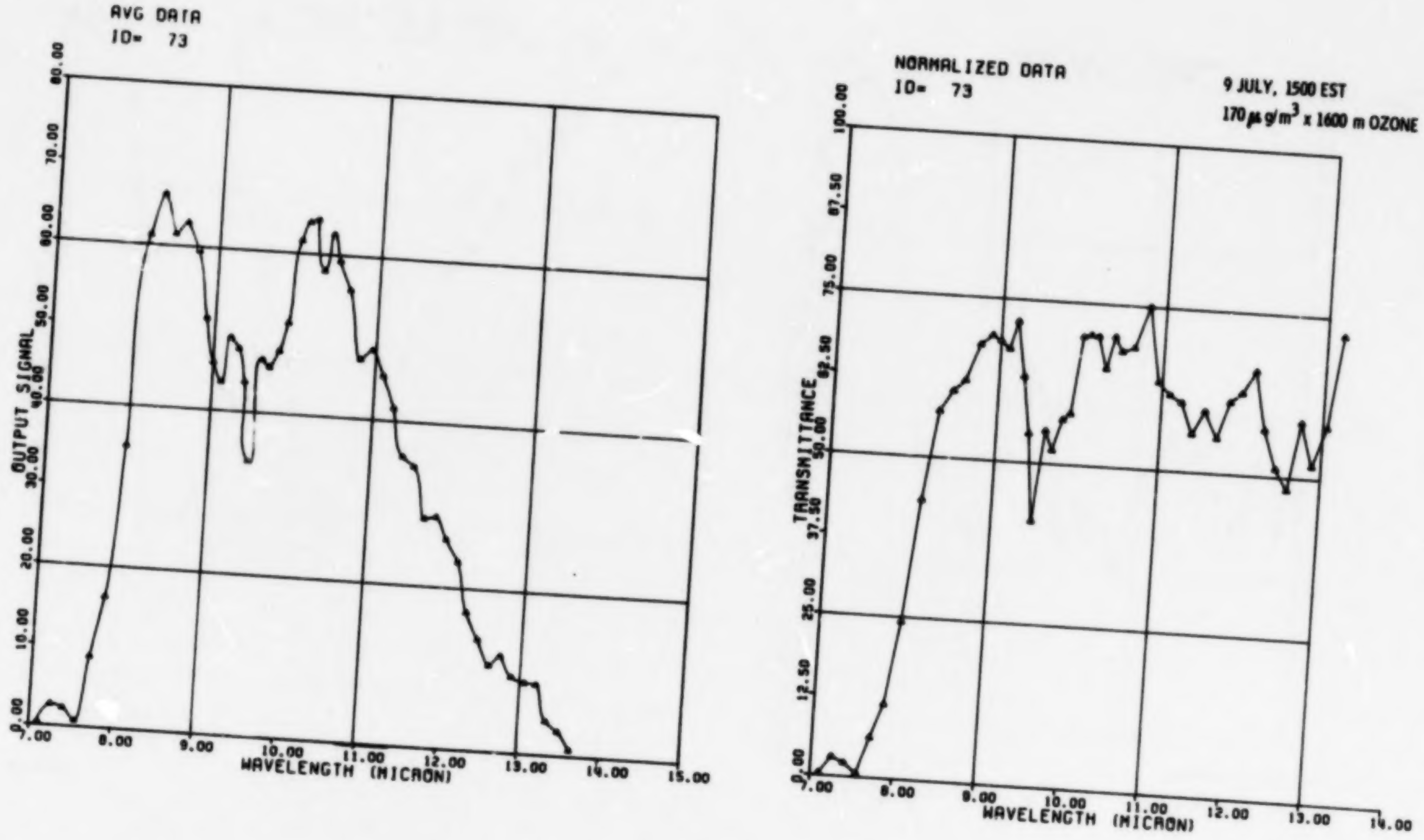


Figure 6-5 Spectra with Ozone Cell in Beam (Page 5 of 7)

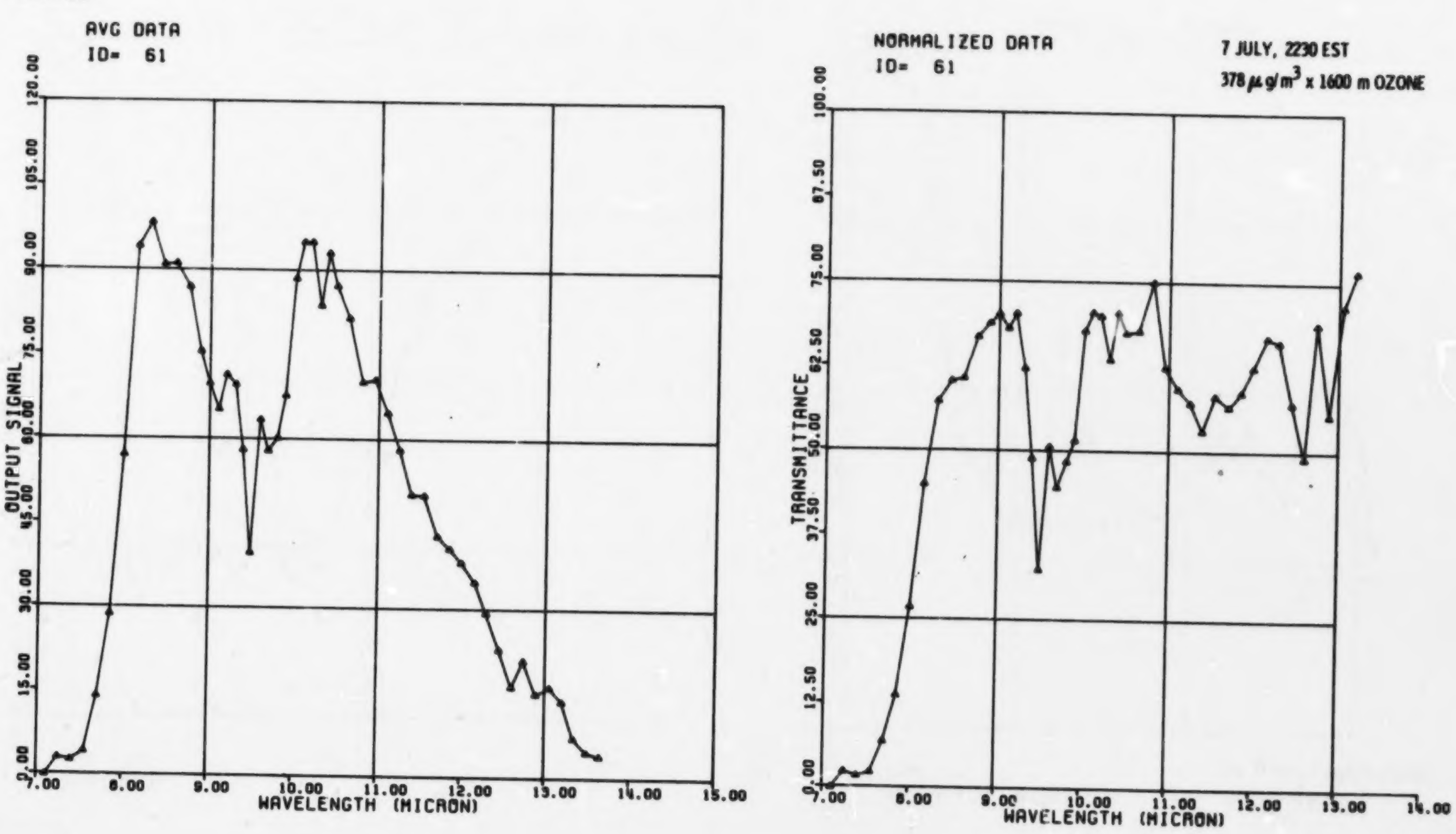


Figure 6-5 Spectra with Ozone Cell in Beam (Page 6 of 7)

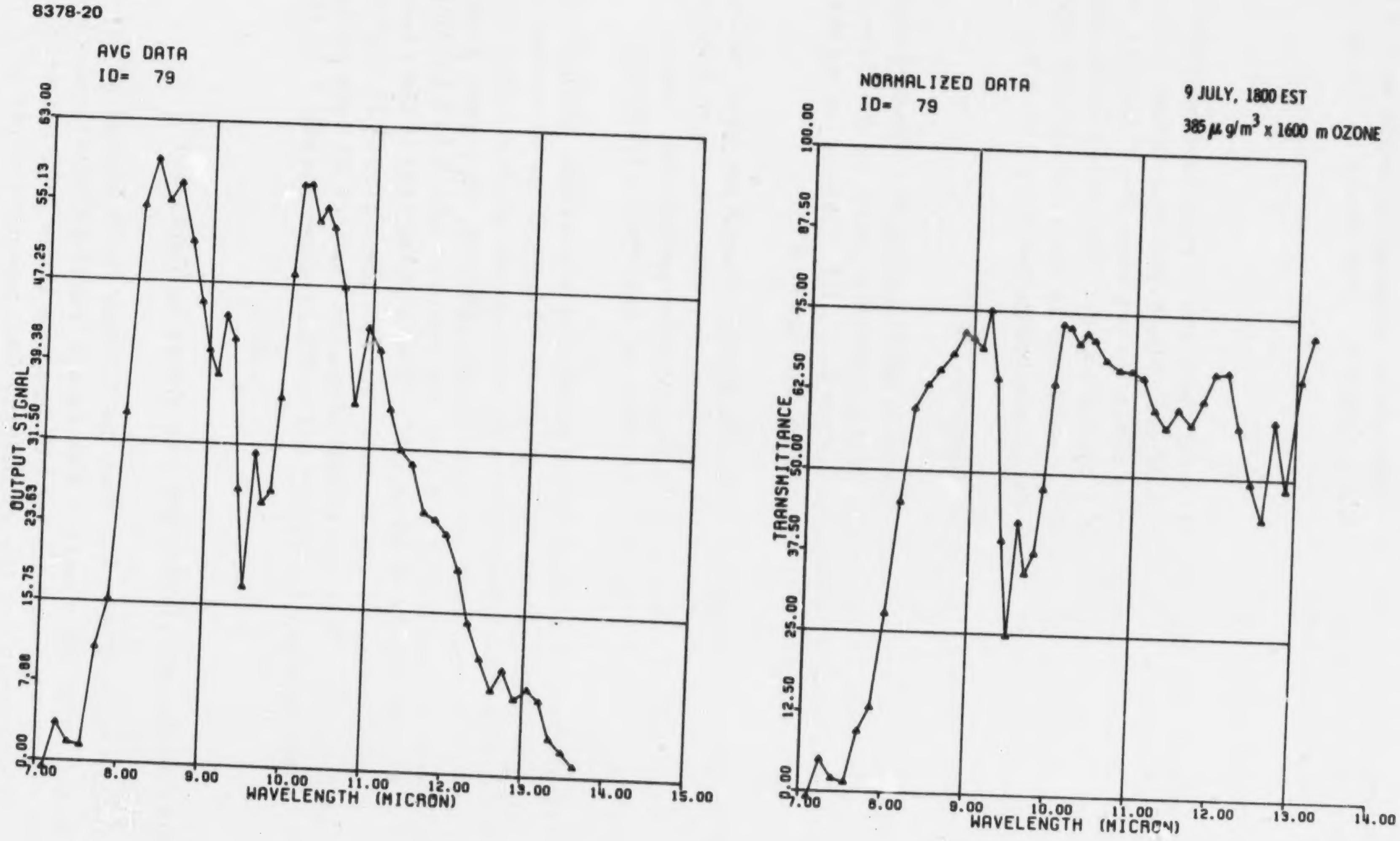


Figure 6-5 Spectra with Ozone Cell in Beam (Page 7 of 7)

Air Pollution Control Administration. The ozone absorption bands at 9.5 and 9.7 μm are clearly visible in the ozone-containing spectra. The cause of the erratic absorption at 10.8 μm is not known.

6.3 PASSIVE-MODE SPECTRA

Figure 6-6 shows two spectra obtained with the instrument operated in the passive mode. Here the source was a rectangular black-painted cavity in the wall of a water tank. The size of the cavity was a little larger than the diameter of the receiver optics, and it was placed about a meter away. The water in the hot source (spectrum shown on the left) was 14.0°C above and in the cold source (spectrum shown on the right) was 12.7°C below the room temperature of 25.5°C.

6.4 ABSORPTION COEFFICIENT OF OZONE

The following calculations were performed to obtain the absorption coefficient K of ozone at 9.7 μm from the spectral measurements made by the Ozone Monitor and the ozone concentration measurements made by Dr. Barnes using the potassium iodide method. The data used are presented in Figure 6-5.

Calculations were made at the 9.7-μm ozone absorption band rather than at the stronger 9.5-μm band, because the width of the wider 9.7-μm band is large compared with the spectral resolution of the ozone monitor and, hence, the results are not very sensitive to instrument bandwidth or spectral calibration.

For each spectrum, it is necessary to find by a baseline method what the output signal would have been in spectral channel 21 (9.69 μm) if no ozone had been present in the beam. It has previously been found by regression analysis that spectral channel 28 (10.40 μm), where ozone does not appreciably absorb, is a good predictor of the output signal in spectral channel 21. From the spectra which had ambient air in the test cell, bearing the ID numbers 55 and 67, it was found that if the channel 28 output signal were multiplied by 0.986 it would predict the channel 21 output signal in the absence of ozone, P_o. P is the actual signal in channel 21 with an ozone concentration path length product CL in the cell. The transmittance τ is given by:

$$\tau = P/P_o = e^{-KCL}$$

The results of these calculations are shown in Table 6-1.

It can be seen from Table 6-1 that the K from ID 78 should be eliminated as being far out of line with the others. The small fractional absorptance in ID 78 and the small ozone concentration both tend to produce large relative errors in their measurement. The average of the remaining four measurements of K (9.7 μ m) is 1.04 m^2/g.

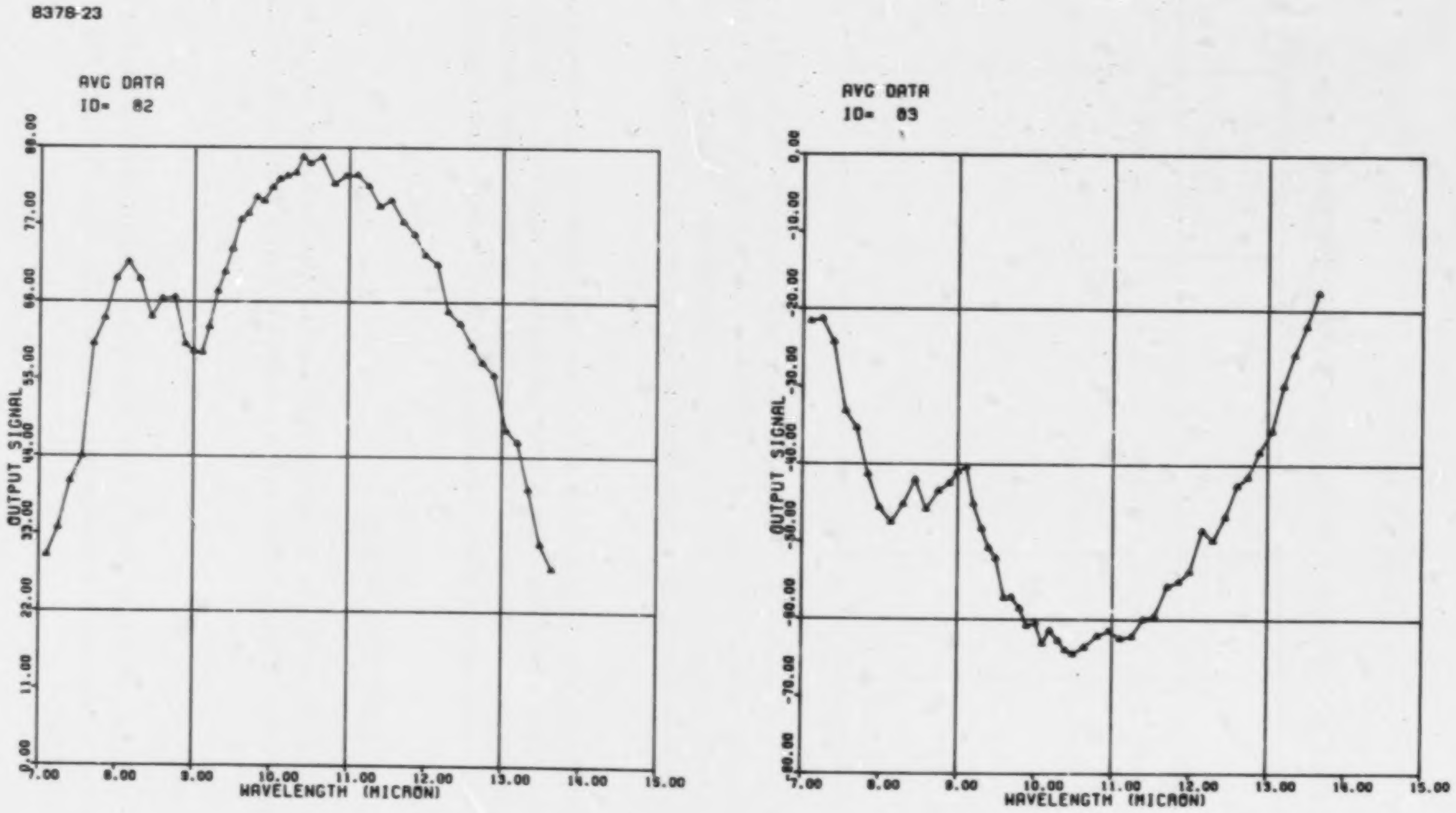


Figure 6-6 Passive Spectra

TABLE 6-1

CALCULATION OF K (9.7μm) FROM SPECTRA

Spectrum ID	Channel 28	P_o	P	τ	KCL	CL (g/m^2)	K (m^2/g)
78	57.9	57.1	51.3	0.898	0.11	0.027	4.0
75	37.7	37.2	30.7	0.825	0.19	0.176	1.08
73	62.5	61.6	45.7	0.742	0.30	0.272	1.1
61	93.0	91.6	57.8	0.630	0.46	0.604	0.76
79	54.8	54.0	25.8	0.478	0.74	0.616	1.2

Dr. R. F. Calfee of The National Oceanographic and Atmospheric Administration, Boulder, Colorado, reports a K (9.7 μm) of 0.29 m^2/g, while from the results of Anding's* survey a K (9.7μm) of 0.42 m^2/g can be calculated. Figure 6-7 shows the absorption coefficients of ozone as a function of wavelength as supplied by Dr. Calfee.

The calibration of the Ozone Monitor is based on independent simultaneous measurements of ozone concentration which are essentially equivalent to measurements of the ozone absorption coefficient. The accuracy of the Ozone Monitor readings is thus, in part, dependent upon obtaining correct ozone absorption coefficients.

6.5 EVALUATION OF OZONE READOUT

Several extended runs were made to evaluate the fluctuations or noise in the ozone concentration readout. These runs were made in Ann Arbor and in Cincinnati

---

*The University of Michigan, Willow Run Laboratories, "Band Model Methods for Computing Atmospheric Molecular Absorption," by D. Anding, Report No. 7142-21-T, AD 815 481, February 1967.

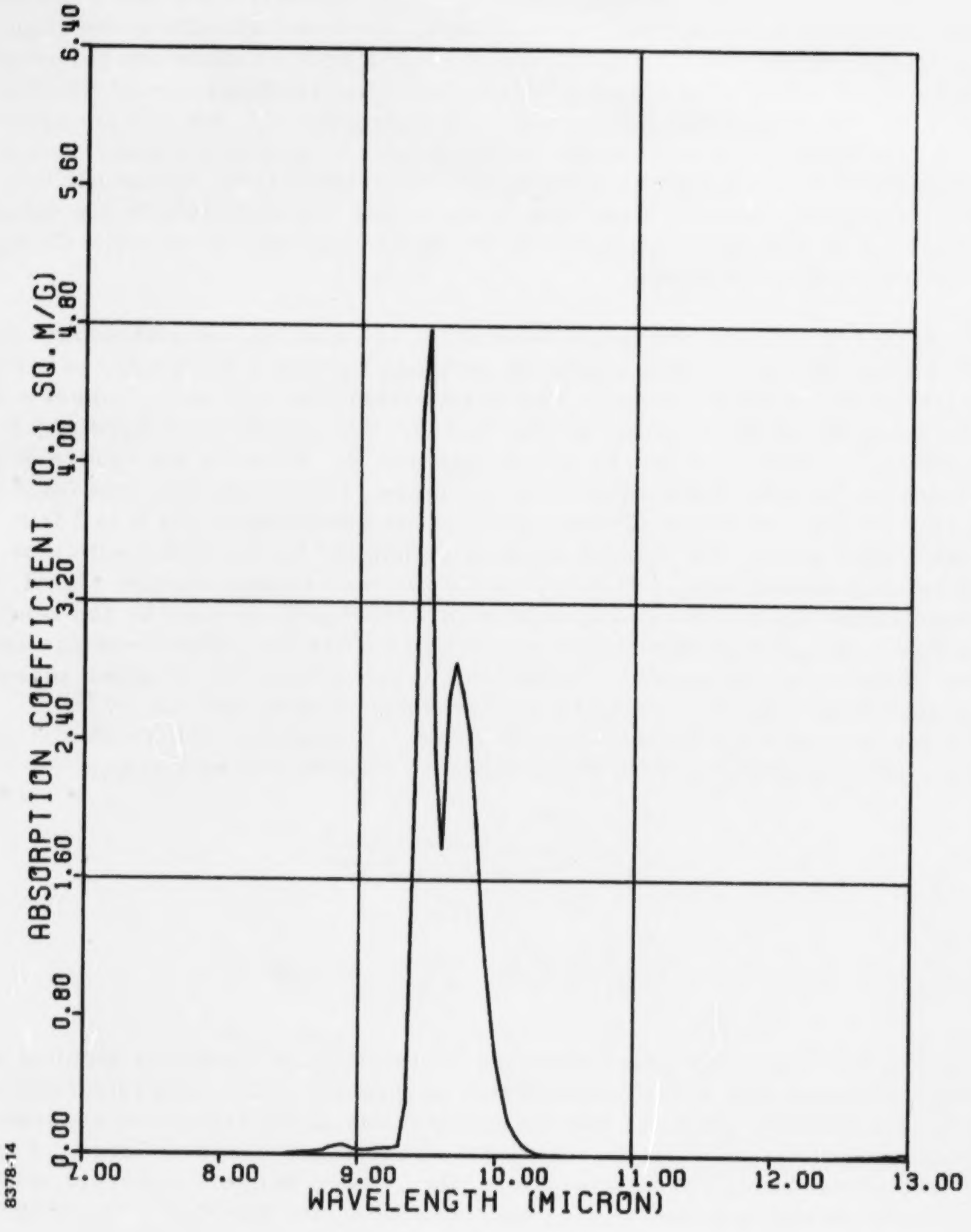


Figure 6-7 Ozone Absorption Coefficients

and at ranges of 1.67 and 1.08 km. Fifty spectral channels were observed during these runs which is a sub-optimum use of time, inasmuch as only seven channels are used in the regression equation. The low-pass time constant for the readings was 145 sec (2.4 min). The standard deviation of the readings varied between 2 and 4 $\mu g/m^3$ which corresponds to about 1% absorptance in the 9.5 μm spectral channel due to ozone. This deviation is due in part to instrument effects such as noise, also includes atmospheric effects such as scintillation, and in addition includes any actual fluctuations with time in the ozone concentration in the optical path. Regression and factor analyses of the spectra showed there were no significant interferences present.

The expected noise in the ozone readout N_o can also be calculated from the measured noise of the individual channel readings N_i, and a knowledge of the coefficients used for each channel. The coefficients used for each channel are scaled to be 10 times those given by Figure 4-3. The coefficients used are 367.9, 318.5, - 876.3, - 341.1, - 384.5, 488.6, and 455.2. Because the square of the output noise is the sum of the squares of the noise in each channel, one finds the square root of the sum of the squares (RSS) of the coefficients and it is 1310. To obtain the output noise, the channel noise is multiplied by the RSS coefficient, divided by the first regression sum $[\mathrm{RGS}(1)]$ (which is the average channel signal, and which normalizes the results to constant signal strength), divided by the range (R) in kilometers, divided by four (which was done to make the output readings conform to values of the ozone absorption coefficients deduced from Dr. Barnes' measurements rather than from Dr. Calfee's coefficients), and divided by $\sqrt{16}$ (to allow for low-passing the output results over 16 spectra). This calculation is performed for the spectrum with ID 60 shown in Figures 6-3 and 6-2.

$$N_o = \frac{N_i \times \mathrm{RSS}}{\mathrm{RGS}\,(1) \times R \times 4 \times \sqrt{16}}$$

$$= \frac{3.7 \times 1310}{80.7 \times 1.6 \times 4 \times 4} = 2.3\ \mu g/m^3$$

Figure 6-8 shows the ozone measurements made by the Ozone Monitor with an ozone-containing cell in the beam plotted against the ozone concentrations reported by Dr. Barnes. One can see the nonlinearity of the fractional absorptance with ozone concentration when the fractional absorptance becomes large. Figure 6-7 can be used as a calibration curve (for 1.6-km range) to convert indicated ozone concentrations to actual ozone concentrations; or, the PDP-8/L computer can be programmed to correct for the nonlinearity in fractional absorptance.

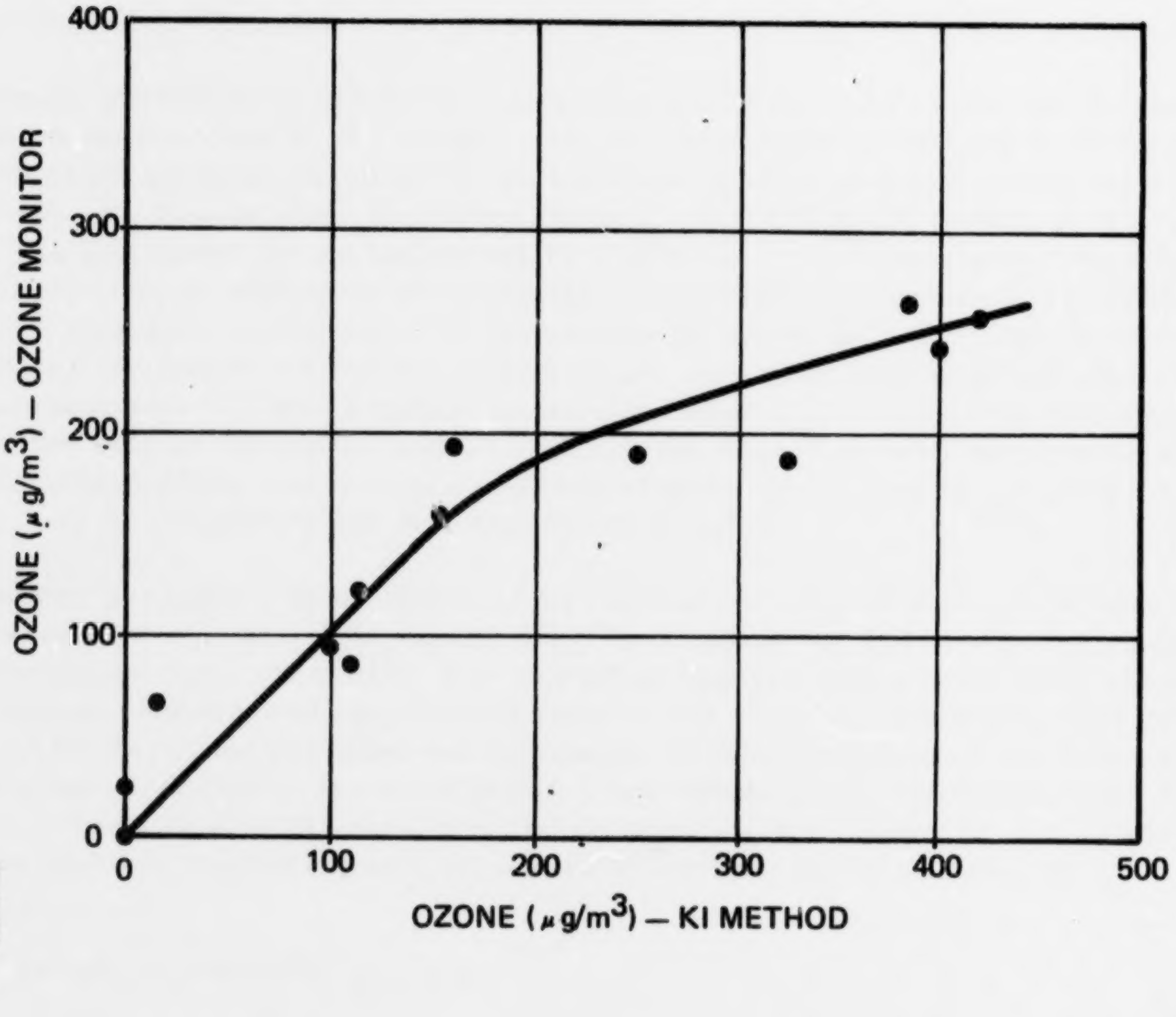


Figure 6-8 Ozone Monitor Readings

The relative error of the data points from the "best fit" line is approximately 15%. This scatter is, of course, due to: imprecision in the potassium iodide (KI) method of measuring ozone, sampling errors, as well as possible fluctuations in the Ozone Monitor reading. Given the uncertainty in the KI method, it is impossible to draw firm conclusions about the Ozone Monitor, but assuming that the precision of the KI method is ± 10%, the precision of the Ozone Monitor readings is also about 10%.

SECTION 7

DISCUSSION AND RECOMMENDATIONS

The Ozone Monitor, as delivered, has met the contract specifications for the instrument. Much more data will, of course, need to be gathered with this instrument, especially in polluted urban environments. These additional spectra will better define the interferences likely to be encountered. A new selection of wavelengths and coefficients will then permit the rejection of these interferences.

Several possibilities for further improvement should be explicitly pointed out. One is an increase in the range. By only looking at seven channels rather than the current general-purpose 50, an increase in duty cycle of seven times can be achieved. By low-passing the ozone readout over 128 more rapidly acquired spectra, the S/N ratio can be increased by $\sqrt{128/16}$ or $\sqrt{8}$ which is 2.8. Also, to the extent that one is willing to increase the instrument time constant above the present 2.3 minutes, additional S/N improvement can be gained. This improved S/N ratio can be traded-off for increased range, and it is estimated that the range can be increased to 3.2 km (2 miles) or perhaps even to 4.8 km (3 miles) with no change in the size of the optics and no appreciable degradation of performance in the measurement of the lower ozone concentrations. (A change in the phase-lock circuitry may be necessary for this increased range.)

Another possibility is an increase in resolution. If it is desired to obtain higher-resolution spectra, this can be done by stepping the filter wheel with fewer steps between spectral channels. The resulting spectra with overlapping channels can be computer-processed (off line) to remove the effect of the instrument response function which degrades the inherent resolution to the resolution of the filter wheel. This computer-processing is described in some detail in the reference cited in Section 3.2.* and is also discussed in the reference cited below.** It is estimated that an increase in resolution to 0.03 μm is achievable by this technique.

---

*R. H. Dye and A. Prostak, op. cit.

**P. A. Jansson, R. H. Hunt, and E. K. Plyler, "Resolution Enhancement of Spectra," Jour. Opt. Soc. Am. 60, 596 (1970).

Additional studies made with this instrument should continue to include independent measurements of the amount of pollutant in the beam, so as to better determine the readings that the Ozone Monitor is expected to produce. This is analogous to the problem of defining "ground truth" for remote sensing instruments.

It now appears that satisfactory results could be achieved with an uncooled infrared detector such as a pyroelectric detector in place of the currently installed mercury-doped germanium detector. The measurements on the Ozone Monitor indicate that its performance exceeds the contract specification and is not now limited by detector noise. As a result, a detector with a larger noise equivalent power could be used with no relaxation of the performance specifications.

Use of an uncooled detector could reduce the size, weight, and cost of an instrument and eliminate the additional complication caused by the detector refrigerator.

When further field studies with the present instrument define firm operational requirements and a limited number of useful spectral channels, a less versatile but simpler, smaller, lighter, and cheaper instrument can be devised.

APPENDIX

DETAILED OPERATING INSTRUCTIONS

A.1 TRANSMITTER UNIT

A.1.1 Operation

The main power switch turns on the chopper motor and two fan motors and also supplies power to the temperature controller. The temperature controller has its own switch. For turn-on, the main power and temperature controller switches should be turned on. For turn-off, first turn off the temperature controller and wait about five minutes for the source to cool, while the fans and chopper are still running. Then turn off the main power switch. This will prevent heat damage to the chopper wheel and other components.

A.1.2 Maintenance

There are two fuses in the transmitter, one before the main power switch and one in the temperature controller.

A polyurethane foam filter is located behind each of the two fans. The filters should be periodically removed when they become dirty, cleaned by washing in water, and reinstalled.

The two mirrors can become quite dirty visually before they need recleaning. They should be cleaned with clean absorbent cotton and alcohol. The window over the silicon cell for the temperature controller should be cleaned occasionally. This silicon cell is mounted on the secondary mirror and can be reached after removing the tubular baffle.

A.1.3 Repair

If the silicon carbide source burns out, it should be replaced with another 80-V source. The source is approached from the bottom of the cylindrical enclosure after the back cover and lower fan are removed. When removing the back cover, it is necessary to unplug the connector that supplies power to the back fan. The sealing material around the heater is chipped away. After the new heater is installed, a piece of the Fibrefrax high-temperature cloth is cut to shape, dipped in Rigidizer, and pressed into place. Some of the high-temperature cement is poured over the cloth to provide, after hardening, an air seal. After about 10 minutes of air hardening, the heater can be momentarily turned on to provide heat to accelerate the curing. The heater should not be turned on for more than a few seconds at a time, unless it is in its normal position where it can be seen by the optical feedback detector mounted in the baffle on the secondary mirror.

A.2 RECEIVER UNIT

A.2.1 Operation

Connect the cables from the main rack to the receiver unit including the ground connector attached to one of the connectors. Attach the cooler control box to the cooler and fan using the two cables supplied. Plug in the power cord for the control box. Point the receiver toward the transmitter. The three-position wheel in front of the vacuum jacket on the cooler should normally be in the clear position. The internal chopper wheel should be locked in the open position with the thumbscrew all the way in for active operation or unlocked with the thumbscrew all the way out for passive operation. It is necessary to remove the outer fiberglass cover and a filter panel to gain access to the three-position wheel or the thumbscrew.

If more than two weeks has elapsed since the last pump-out of the vacuum jacket, it will probably be necessary to repump the vacuum jacket. It is necessary to remove the outer fiberglass cover and a filter panel to gain access to the vacuum jacket.

> ONLY CONNECT THE MAIN DETECTOR TO THE PREAMPLIFIER WHEN THE "SYSTEM" OR "RECEIVER ELECTRONICS" SWITCH ON THE CIRCUIT BREAKER PANEL IS TURNED OFF.

Turn on the switch in the cooler control box when a cold detector is desired for operation. Cool-down time is approximately 15 minutes.

A.2.2 Maintenance

Occasionally, it will be desirable to remove, wash, and reinstall the four foam filters on the receiver unit.

When the cooler stops operating properly it will have to be returned to the Malaker Corporation for repair. (See Malaker Cooler Manual). The time between repairs is claimed to be greater than 500 hr operating time. It is suggested that the flanged cylinder holding the cooler be removed from the receiver. Then remove the blower from the flange and remove the cooler from the outer cylinder by removing the three nylon set screws at the rear of the cylinder and the three screws at the front of the cylinder. The cooler will then come out of the cylinder. The vacuum jacket should be left on the cooler when shipping the cooler for repair.

Side-to-side and up-down adjustment of the detector for optical realignment is obtained by moving the large cylinder on the vertical plate to which it is attached. This is accomplished by removing or loosening the bolts on the bolt circle holding the large cylinder and adjusting the three set screws on the side of the cylinder that positions the large cylinder. After the adjustment is completed, the bolts should be replaced and tightened.

In-out adjustment of the detector is made by sliding the small flanged cylinder that holds the cooler. Three thumbscrews and four regular screws work in opposition to control the in-out movement of the small cylinder.

Focusing of the collecting telescope is accomplished by loosening the nylon set screws on the secondary mirror threaded shaft, loosening the locking ring and rotating the threaded shaft. This moves the secondary mirror in and out. The set screws can slightly tilt the secondary mirror.

To allow adjustment and refocusing, most of the parts are not pinned. Therefore, after disassembly the parts cannot be easily returned to their present relative positions. Consequently, the bolts holding the various optical elements and the cooler should not be loosened unless realignment is desired.

After 500 hours of use, the oil in the stepper motor should be changed. The oil should be drained (by inverting the motor) and the motor refilled with 5 ml of approved* oil. Failure of the motor to step properly at high speed, especially in cold weather, may be due to too much oil. The motor can be partially drained of oil without harm.

FWREF is found as follows. The built in polystyrene film (or any other material with known absorption bands) is inserted in the beam. A filter wheel position list is used that has closely spaced (one-step) increments in the vicinity of a known polystyrene absorption band and that also includes a filter wheel position on the other side of FWREF to assure that the slit in the filter wheel rim will pass by the light. Spectra are then taken. The minimum signal in each spectrum should be at the filter wheel position shown in Table 2-2 as corresponding to the wavelength of the known absorption band. If the minimum is not at the correct filter wheel position, FWREF is changed slightly so as to bring the spectrum minimum to the correct filter wheel positions. The known absorption band on which the calibration is based should be near a wavelength of interest (e.g., 9.7 μ for ozone measurement). Extremes of ambient temperature cause the interference films on the filter wheel to expand or contract and will probably require a change in FWREF to maintain the wavelength calibration.

---

*USM Spec 66 BR Lubricant, USM Corporation, Gear Systems Div., 5033 Balch St., Beverly, Mass. 01915 or Humble Oil Spinesso-34.

Lubrication of the tripods is required twice a year. Put one drop of light lubricating oil on the threads of all clamp screws; on each side of the joint where legs are hinged to tripod plate, and on hinge joints at both ends of leg struts. Do not apply any oil to lower legs or strut tube. The horizontal and vertical pivot and anti-friction bearings on the pan heads are permanently lubricated. Twice a year apply one drop of light lubricating oil to the threads of clamp screws. Apply one drop of lubricating oil to hand wheel shaft bearing of the gear drive.

A.3 MAIN ELECTRONICS RACK

A.3.1 Operation

Plug the Teletype power cord into the back of the switch panel and join the connectors on the Teletype signal cable. Plug the main power cable into a source of 117 V, 60 Hz single-phase AC power. Throw the main power switch on. Turn on the oscilloscope and the cooler switch (on the cooler control box). All the other switches on the switch panel can be turned on except for the chopper switch if the instrument is to be using the active source unit. For passive operation, with the internal receiver chopper unblocked, the chopper switch should be turned on. The computer should be turned on and the mode switch set to active or passive as appropriate.

The manual for the PDP-8/L computer supplied by the Digital Equipment Corporation should be consulted for details of computer operation. In brief, the group of 12 keys in the middle of the computer comprise the SWITCH REGISTER. The switches in the SWITCH REGISTER are grouped in threes, corresponding within each group to the digits 4, 2, 1 from left to right. The sum of the digits selected in any group gives the octal number for that group. For example, the first switch and the third would be 4 + 1 or 5. If every other switch in the switch register were up starting with the first one, the number would be $(5252)_8$, and if all were up the number would be $(7777)_8$. The number $(0200)_8$, corresponding to the starting address of the OZONE MONITOR main program, is made by lifting the second switch in the second group. Some references in this manual are to a specific switch starting from the left side of the SWITCH REGISTER numbered 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11.

The Ozone Monitor program ("everything" tape) is loaded with the binary loader. The starting address of the Ozone Monitor program is 0200. Therefore, set the computer switch register to 0200. Depress LOAD ADDRESS switch. The number 0200 should appear on the Program Counter lights. Depress START switch. The computer RUN light should turn on. If the detector is cold, normal operation can commence. If an error halt occurs, the computer can be reinitialized by depressing CONT (Continue) or by reloading the start address (0200).

A slit is provided in the rim of the filter wheel. A light source and a phototransistor are arranged such that when radiation of a certain wavelength in the image passes through the filter wheel, the light from the lamp passes through the hole in the filter wheel and actuates the photodiode. This is fed to the computer in the form of a reference pulse which the computer expects at the same point in every scan. The computer stops the operation if it fails to receive the pulse when it is expected. If either the lamp of phototransistor is changed in position or the detector image on the filter wheel is changed, the reference pulse will occur at a different position and should be checked by observing something with a known spectral absorption, such as the built-in polystyrene film, to assure that it is in the same position. If the entire spectrum is shifted up or down in wavelength, the position of the reference pulse should be changed accordingly in the software by depositing a new channel number into memory location 0137. The present channel number corresponding to the filter wheel reference pulse is 0373_8. If switch register switch no. 10 is lifted, the program automatically (in effect) "continues" if a filter wheel error is encountered.

As a guide to receiver alignment, it has been found that on a somewhat hazy day at 1.6 km (1 mile) range, the auxiliary channel signal (oscilloscope channel 1, switch position 11) was 0.50 V peak to peak. The signal for filter wheel position 275_8 was 1.2 V on the bar chart. (To look at this single bar, load 0001 in location 0176_8, and load 0275_8 in location 4100_8. To return to the 50-channel bar chart, load 0062_8 in location 0176_8, and the first filter wheel position (0011) in location 4100_8.

To maximize the receiver signal when the oscilloscope can not be seen from the receiver, the hand-held multimeter can be used. Using a BNC-to-alligator clip connector, attach the multimeter leads to the channel 1 output on the control panel and observe the main integrator output (oscilloscope channel 1, switch position 9) on DC volts. A single strong channel should be used, either by using a one-channel filter wheel position list or by lifting computer switch no. 2. Align the receiver to maximize the main integrator output.

To turn off the instrument, first press the STOP switch on the computer. Then turn off the computer with the key switch.

CAUTION

> DO NOT TURN OFF THE POWER TO THE COMPUTER WHILE IT IS EXECUTING (RUNNING). THIS MAY CAUSE THE OZONE MONITOR PROGRAM IN THE COMPUTER MEMORY TO BE CHANGED, NECESSITATING A RELOAD OF THE PROGRAM "EVERYTHING" TAPE INTO THE COMPUTER.

A.3.1.1 Control Panel

The control panel to the right of the oscilloscope has two rows of five pushbutton switches to communicate with the computer. The lights behind most of these switches are computer controlled.

Top Row

DISABLE COMPUTER INTERRUPT - This switch at the top left is pressed ON when it is desired to disable computer interrupts from the ozone monitor hardware. This would be done if one wanted to use the computer as a normal PDP-8/L computer without interaction with the Ozone Monitor equipment. For normal ozone monitor use, this switch should be OFF as indicated by the light behind it being OFF.

LO PASS - When this switch is ON and if the detection processing switch is ON, the indicated ozone concentrations are low-passed as provided in the Ozone Monitor program in the constant INTC where INTC is currently 4, producing a low-pass time constant of 2^4 or 16 spectra. This reduces the noise by $0.8 \times \sqrt{16}$ or a factor of 3.2. If the LO PASS switch is OFF, there is no low passing.

DETECTION PROCESSING - This switch when ON causes the computed ozone concentration to be output on the Teletype - currently after every fourth spectrum.

PRINT DATA - This switch when ON causes the spectrum to be printed on the Teletype in decimal notation. While the Teletype is printing the spectrum at 10 characters/second, additional spectrum gathering is suppressed. The fifth blank switch button is a spare that can be used when modifying the Ozone Monitor computer program to provide additional capability.

Second Row

TIMES 4 - This switch increases the resolution and size of the spectrum bar chart that can be displayed on the oscilloscope by a factor of 4. The magnified bar chart display is also four times closer to the maximum signal that can be displayed without numerical overflow. Numerical overflow at the D/A converter causes a large positive number to be displayed as a negative bar in the downward direction. Hence, the TIMES 4 switch should be ON for weak signals, such as are received at 1.6-km range, but should be OFF for strong signals, such as are received at 0.4-km range.

LINE LOCK - This switch is not currently used. The light in the switch is ON when the instrument is in the active mode and the auxiliary signal is too small to supply timing information. Hence, the circuitry changes from signal lock to line lock. (Occasional noise pulses may appear large enough to lock onto so that the light may flicker off.)

INCREMENT I.D. - This switch is pressed and released to increase the identifying number associated with a spectrum or group of spectra.

PUNCH DATA - This switch, when depressed, causes the spectra to be punched on the high-speed punch. Obtaining the spectra in this way does not slow down the rate of gathering spectra.

The last blank switch is not currently used.

The leftmost connector receptable is controlled by the left 24-position switch on the interface panel and is normally connected to the left oscilloscope channel (Oscilloscope Channel #1). The middle connector receptacle is controlled by the right 24-position switch on the interface panel and is normally connected to the right oscilloscope channel (Oscilloscope Channel #2). The rightmost connector receptacle is controlled by the three-position switch on the interface panel and is normally connected to the oscilloscope trigger synchronizing signal input. The Tektronix Oscilloscope Instruction Manual contains detailed information on oscilloscope operation and maintenance.

A.3.1.2 Analog-to-Digital Converter

In normal operation the A/D Converter word length switch is left on 12 and the power switch is left ON. The three other rocker switches are not normally used.

A.3.1.3 Interface Panel

The left 12-position switch on the interface panel is normally on position 1 for spectrum bar chart display. The other positions are used for setup and troubleshooting. The three-position sync switch should be on BAR chart sync for bar chart display.

The right 24-position switch and the power supply multiple position switch below it are not normally used but are useful for troubleshooting.

Table A-1 shows the circuit locations that can be easily examined on the oscilloscope by using these two 24-position switches. Of course, any other location can be examined by using the oscilloscope probe.

A.3.1.4 Teletype Controls

The switch on the right side of the Teletype unit has three positions: LINE, LOCAL, and OFF. The LOCAL position allows the operator the control of the instrument for punching out tape or for any other reason (i.e., merely using the typewriter). The LINE position assures a direct link with the computer for reading in programs, or punching or typing out responses (data collection, program parts, detection processing, etc.). Switches on the punch panel on the left of the Teletype control the tape-punch operation - on or off, back space, and release. On the lower left is a switch with three positions: START, STOP, and FREE. These control the tape read-in mode to the computer. The tape is secured mechanically into the reader by a latch in such a way that the tape advance sprockets must be in the tape perforations.

A.3.2 Phase Lock Check

The phase lock circuit should be checked after setting up at a new location as follows.

Confirm that the remote chopper is locked to the local line frequency by putting the oscilloscope on line sync and observing the auxiliary signal (channel 1, switch position 11). The aux signal should be stationary on the screen and not drift.

Confirm that the phase lock circuit is locked on the auxiliary signal by putting the oscilloscope on line sync and simultaneously looking at 60-Hz sine wave (channel 1, switch position 17) and a nominal 60-Hz square wave obtained from the phase lock circuit (channel 2, switch position 17). The two waves should remain in constant relation to each other. If there is drift of the square wave relative to the sine wave, the phase lock circuit is not locked on the auxiliary signal.

TABLE A-1

TEST PANEL SWITCH POSITION IDENTIFICATION

Position	Channel 1		Channel 2	
1	B12B2	Bar Chart		Power Supplies
2	J6B	Main Detector "I" Bias	J6A	Main Detector "E" Bias
3	SE20	Filter Wheel CCW Rotation	SE22	Filter Wheel CW Rotation
4	J6C	Main Detector Signal	A6J2	Filter Wheel Index Pulse
5	B20V2	Main A. R. C. 1	A6P2	Filter Wheel Complement
6	B20U2	Main A. R. C. 2	A6V2	A. R. C. Gain (Log)
7	B16N2	Main (-) Complement	B16U2	Main (+) Complement
8	B19V2	Main Demodulator	A19N2	AUX (+) Complement
9	B19K2	Main Integrator	B6N1	Dump Complement
10	B19L2	Multiplexer	B19J2	Select Main Complement
11	J6E	Aux. Det. Signal		Spare
12	A20J2	Aux. A. R. C. 1		Spare
13	A20H2	Aux. A. R. C. 2	SW5-2	Phase Reference
14	A19R2	Aux. Demodulator		Spare
15	A19U2	Aux. Integrator		Spare
16	A4U2	5 CR Trigger	A4H2	Ramp
17	SW3-1	Line Sync	A15V2	60
18	A6K2	Receiver Chopper	A15S1	120
19	A14M2	AFC Voltage	A15P2	240
20	A16M2	AFC Phase Demodulator	A15L1	480
21	A16H2	AFC Integrator	A15H2	960
22	B16J2	AFC Sample	A15E1	1920
23	B16K2	AFC Dump		Spare

To attempt to have the phase lock circuit lock on the auxiliary signal, first block the beam. The phase lock circuit should now lock on the local line frequency. Then unblock the beam and the phase lock circuit should lock on the auxiliary signal. If it does not, the voltage-controlled oscillator (VCO) control (on card 14 A in the interface unit) may need slight adjustment. This control is very touchy and should only be moved a very small amount.

When the phase lock circuit is locked on the auxiliary signal, examine the automatic frequency control (AFC) voltage (channel 1, switch position 19). The AFC voltage should be 0 ± 1 volt. If it is out of this range, the VCO control should be slowly and deliberately adjusted to bring the AFC voltage within the above range. Only a very small adjustment should be necessary.

Finally, the trace on oscilloscope channel 1 switch position 20 should look as shown in Figure A-1 (a). If the oscilloscope trace looks as shown in Figure A-1 (b), then the AFC offset voltage (marked "0" on card 16) should be adjusted until the vertical breaks occur at extrema of the wave form.

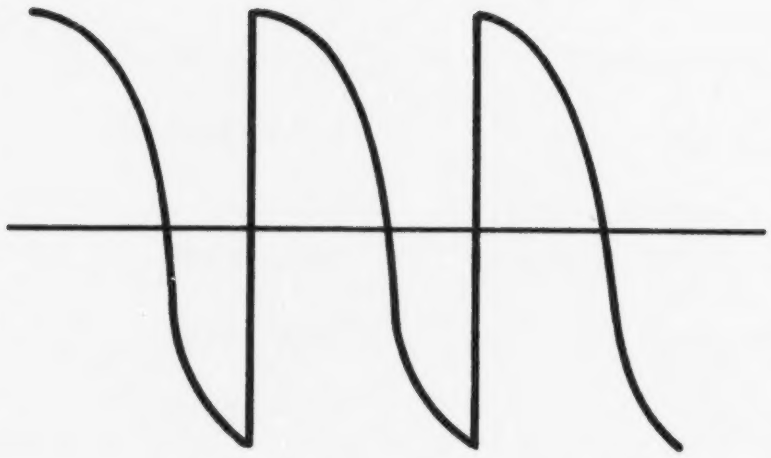
A. 3. 3 Maintenance

The polyurethane foam dust filter on the top of the cabinet should be occasionally removed, washed, and replaced.

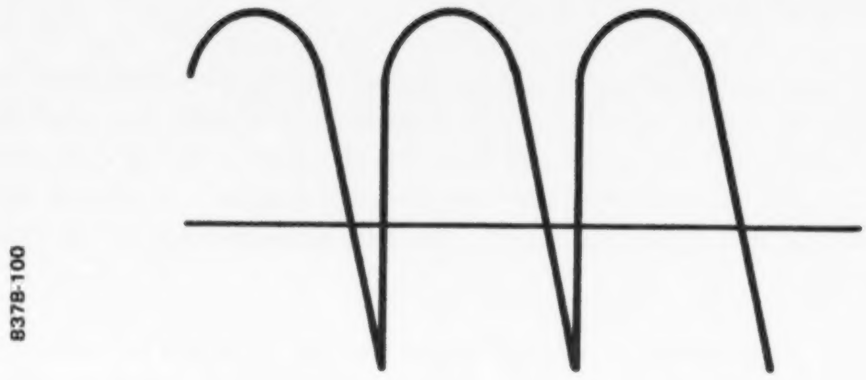
A. 3. 4 Repair

The following circuit diagrams are provided in accompanying envelopes. They will permit troubleshooting and repair, should it become necessary. The diagrams are identified by title and drawing number.

System Cabling Diagram	BSX 10815
Circuit Breaker Panel	BSX 10813
Control/Display Panel	BSX 10802
Interface Chassis	BSX 10803
Phase Lock	BSX 10807
Line Receivers and ARC D/A	BSX 10812
Automatic Range Control Amplifiers	BSX 10805



a. Good



b. AFC Offset Needs Adjustment

Figure A-1 Oscilloscope Trace From AFC Phase Demodulator

Auxiliary Preamplifier	BSX 10814
Main Preamplifier	BSX 10808
Receiver Electronics	BSX 10801
Fotofet Amplifier	BSX 10809
Synchronous Demodulators, Integrators, and Multiplexer	BSX 10806
Stepper Regulator	BSX 10804
D/A Converter	BSX 10811

To gain access to the wire-wrap pins on the plug-in card receptacles in the interface chassis, it may be necessary to remove some of the screws that fasten the metal frame (that holds the card receptacles) to the slides. The metal frame can then be rotated 90° using two remaining screws (one on each side of the frame) as a pivot. In this position, the wire-wrap pins are accessible.

A. 4 USING THE COMPUTER SOFTWARE

All control of the system is initiated at the computer console and is implemented by commands from the user to the computer through the control panel switches. The brief description here of the switches on the computer console should enable the operator to use the system successfully. A more detailed explanation can be found in the DEC Small Computer Handbook* or in the PDP-8/L Users Handbook. **

On the bottom of the PDP-8/L operator console is a row of 22 keys. The middle group of 12 keys comprise the SWITCH REGISTER. The switches in the SWITCH REGISTER are grouped in threes, corresponding within each group to the digits 4, 2, 1 from left to right. The sum of the digits selected in any group gives the octal number for that group. For example, the first and third switches would be 4 + 1 or 5. If alternate switches were in the up position starting with the first one, the number would be $(5252)_8$; if all were in the up position, the number would be $(7777)_8$. The number $(0200)_8$, corresponding to the starting address of the Ozone Monitor main program, is made by lifting the second switch in the second group from the left. Specific switches are numbered 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11 starting from the left side of the SWITCH REGISTER.

---

*DEC Small Computer Handbook, Digital Equipment Corporation, Maynard, Massachusetts.

**PDP-8/L Users Handbook, Digital Equipment Corporation, Maynard, Massachusetts, 1968.

Before the computer can respond to operator control for data gathering or detection processing, it must be loaded with a binary tape containing the programmed instructions for this application.

A. 4. 1 Loading the Binary Tape

Turn the computer power key on. Put the Ozone Monitor "everything" tape in the high-speed tape reader. Turn the reader on. Set the Switch Register to 7777 and depress the LOAD ADDRESS switch. The number 7777 should appear on the Program Counter lights. Put switch number 0 in the down position and press the START switch. The computer should now be reading the contents of the tape into its memory as evidenced by the physical reading of the tape in the reader. If nothing happens when the START switch is depressed, the operator should repeat the above steps. If the tape is still not being read, it will be necessary to reload the BINARY LOADER.

To make small changes in the program in the computer by overwriting the program from the "everything" tape, make a change tape using the punch on the Teletype in the LOCAL mode. The format of this change tape is analogous to that used in using the computer switch register to change the program. It is

```
XXXX/YYYY (CR) (LF)

ZZZZ (CR) (LF)

etc.
```

where XXXX is the address in which YYYY is to be deposited. ZZZZ is deposited in the next address location. CR and LF are "carriage return" and "line feed." To load the change tape, place the tape in the Teletype reader. Set the Switch Register to $(7400)_8$ and depress LOAD ADDRESS. Turn on the Reader and depress START.

A. 4. 2 Loading the Binary Loader

The set of standard DEC tapes supplied with the computer contains one labeled BINARY LOADER. This tape contains instructions that enable the PDP-8/L to read binary encoded programs (the Ozone Monitor program is an example). Put the Binary Loader tape in the Reader. Set the Switch Register to 7756 and press the LOAD ADDRESS switch. Put the first switch (number 0) in the down position and press START. Additional details of the Binary Loader routine can be found in the software manuals supplied with the computer, and it is suggested that the user consult this documentation. If the Binary Loader does not load properly, the Rim Loader should be checked. This short series of manually loaded instructions is described in the software manual which should be consulted in the event of failure to load the Binary Loader. Successful loading of the loaders is then followed by a repetition of the steps listed above for loading the Ozone Monitor binary tape.

A. 4. 3 Initializing the Program

The software is ready to use upon successful loading of the binary tape, as indicated by the number of 0000 appearing in the accumulator after the tape has been read into the computer's memory. To begin operation, place the number $(0200)_8$ in the Switch Register and press LOAD ADDRESS. This number, which is the starting address of the Ozone Monitor main program, should appear on the Program Counter lights. To start the instrument, press the switch labeled START. This operation enables the software to begin exercising its control over the instrument and its data. This control will be apparent to the operator because he will be able to see and hear the filter wheel stepping to and stopping at the positions at which it is to take readings. The instrument is now ready to be operated in any of the ways previously described. While in the data-gathering mode, the user may desire a punched paper tape containing the list of filter wheel positions being used. To obtain this hard copy, press STOP, load 0200, the starting address of the main program, power the high speed punch, lift up switches 1, and 11, and press START.

Occasionally it may be necessary to stop the instrument. This can be done in either of two ways: (1) depress the STOP switch, or (2) lift up switch number 2. The advantage of the second method is that the last spectral scan completed will remain displayed on the oscilloscope screen. To resume data taking, push CONTINUE in the first case or depress switch number 2 in the second case.

It may prove convenient during system checkout to suppress the error halts that result from the inability of the filter wheel to find its reference point on a spectral scan or from signals too large for processing (A-D overflows). This will result in the generation of a HALT instruction by the software and suspension of all instrument activity. To prevent delay, the software can be made to ignore these errors by lifting switch number 11. If the error halts are not suppressed in this manner, the system will stop gathering data. To resume activity, the spectrometer has to be reinitialized. This will be done automatically if switch number 10 has been lifted. The upper-right light on the control panel will go on when the software is setting up the initial conditions for operation. When the program is halted by one of the error sub-routines, the address of the error routine will generally appear in the program counter lights. This permits diagnosis and corrective action should this error occur too frequently.

The following instructions should be followed to generate the bar chart spectral display on the scope:

1. Set the Channel Selector No. 1 on the control console to position No. 1. This position allows monitoring of the output from the A/D converter. Also set the switch to BC, bar chart synchronization.
2. Trigger the scope on EXT sync and set the time scale to 0.1 millisecond/div.
3. Channel No. 1 should be viewed at a gain of about 1 volt/div.
4. The scope settings can be varied from those given here to suit the viewing preferences of the operator.

When viewing spectra at long range, it may be desirable to multiply the channel readings by a factor of four to increase the oscilloscope digital resolution. For this purpose, a TIMES 4 button can be pushed on the operator console. If one merely increased the scope gain, the height of the observed spectrum would increase, but the digital resolution would not be increased. As a result, one would be observing truncation error and the finite number of digital steps allowed.

Another button on the control console is the upper-left button. This button, which prevents the interface unit from generating interrupts to the computer, should be pushed in when the computer is being used in a noncontrol capacity. Such a use would be testing the PDP-8 or peripheral devices with standard DEC MAINDEC Maintenance Routines. In this case, one would not want interrupts to disrupt the program.

The value of C is in $\mu g/m^3$, providing that the value of 4 × L is placed in the double-precision constant RNGC (for range constant). The 4 comes from the factor necessary to convert the values of the ozone absorption coefficient K obtained from Calfee to those obtained by Barnes and the L is the range in kilometers. The number 4 × L should be in octal with the octal point between the two words. For a range of one mile or 1.609 km, 4 × L = $(6.4375)_{10}$ = $(6.340)_8$. Then RNGC=0006 3400. For the concentration readings to be correct, this number must be changed every time the range is changed.

A.4.4 Control Fuctions of Switch Registers

Following is a summary of the special-purpose switches of the Switch Register:

Switch No.	Function
1	PUNCH POSITION LIST. If lifted, the program punches on paper tape the filter wheel position list when in the INIT subroutine.
2	STOP ACTION. If lifted, the computer stops the filter wheel at its present location. The integrator continues to integrate signals. The last complete spectrum gathered remains displayed on the scope.
10	FILTER WHEEL ERROR HALT SUPPRESSION. If lifted, the program returns control to the INIT subroutine when filter wheel errors are encountered.
11	HALT SUPPRESSION. If lifted, the program suppresses halts which occur from A/D format overflows and filter wheel errors.